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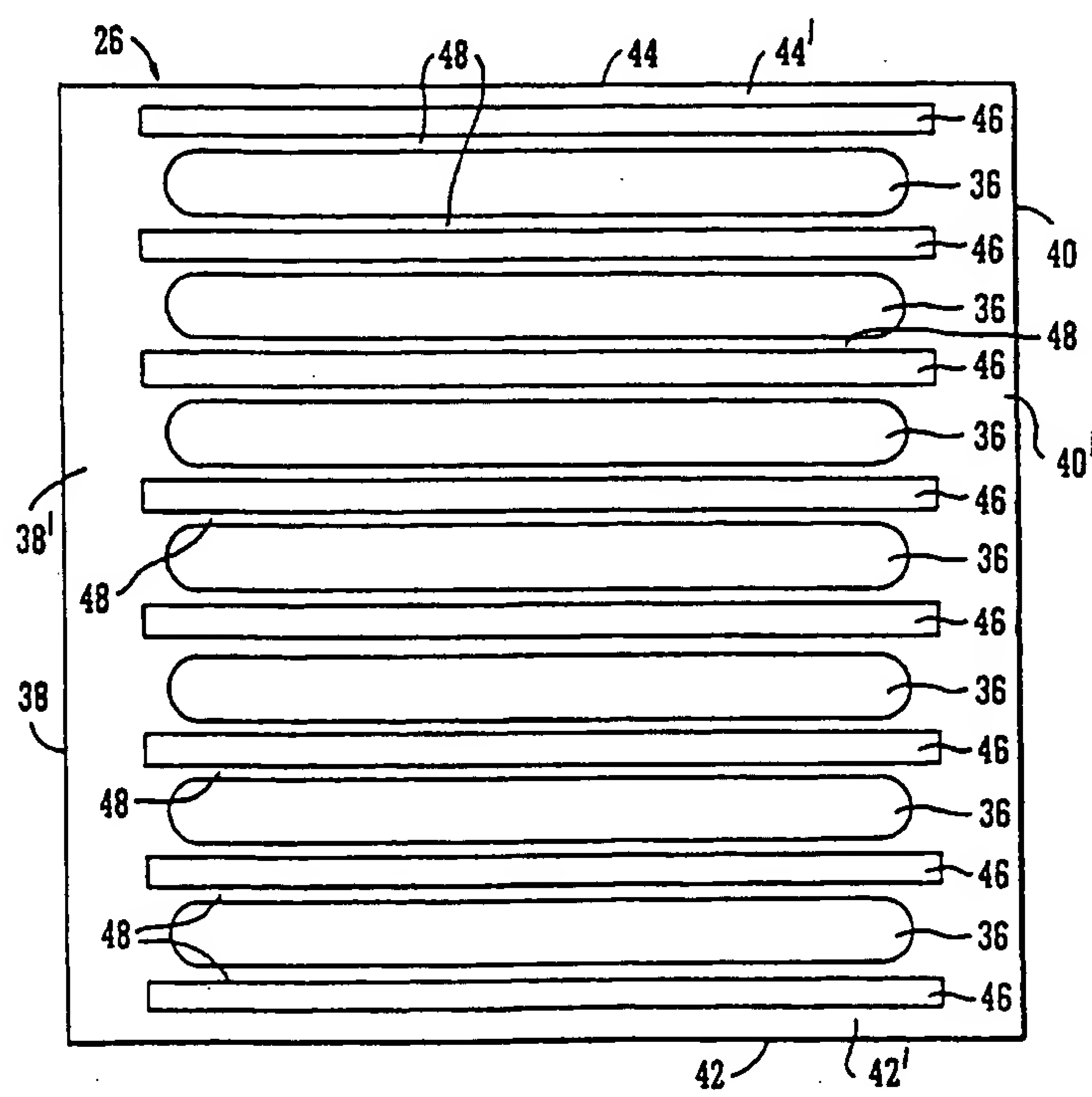
(54) Title: HEAT EXCHANGER

(57) Abstract

A heat exchanger, particularly useful as a packed bed catalytic reactor, comprises a stacked assembly of plates, the stack having an inlet (12) and an outlet (14) for a first fluid and an inlet (24) and an outlet (34) for a second fluid, characterised in that a first portion of the assembly is formed of one or more perforated plates (26), each first perforated plate (26) having two alternating series of slots (36, 46), whereby the series of slots (36, 46) define two separate passageways for said two fluids, the first series of passageways being connected to said inlet (12) and outlet (14) for the first fluid, a second portion of the assembly being formed of one or more second perforated plates (20, 22, 20A) having first (36A, 36B) and second (46A, 46B) series of slots corresponding to the slots of the first plate(s), each slot (46A, 46B) of the second series opening at one of its two ends into a feeder slot (50, 50B) extending across the second plate, the feeder slot(s) being connected to an inlet (24) or an outlet (34) for the second fluid.



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DESCRIPTION

HEAT EXCHANGER

This invention relates to heat exchangers. It is particularly concerned to provide a heat exchanger that can be used as a packed bed catalytic reactor.

However, it will be appreciated that the invention is not intended to be limited to use as packed bed catalytic reactors and a structure of the invention may be used, for example, as a "bulk fluid" heat exchanger wherein one of the fluids passing through the structure comprises granules or powder constituents. Structures of the invention may equally, if desired, be used to exchange heat between two liquids, two gases or between a gas and a liquid. Nevertheless, the invention will for convenience be more particularly described with reference to packed bed catalytic reactors.

In a packed bed catalytic reactor it is necessary to pass a first fluid or mixture of fluids, which is to react in a desired manner, into contact with a bed of a catalyst which promotes the reaction. The reaction may be exothermic, in which case it may be necessary to cool the reacting fluid(s), or endothermic, in which case it may be necessary to heat the fluid(s) to promote the desired reaction. In both instances, it will be appreciated that a heat exchanger structure may usefully be employed so that heat may be added to or taken from the fluid(s) passing into contact with the catalytic material.

Known heat exchanger constructions for use as packed bed catalytic reactors are generally based on existing tube and shell technology and hence are not as efficient in terms of performance per unit volume as would be reactors of more compact construction. It is, therefore, an object of the present invention to provide an improved construction that is particularly useful as a packed bed catalytic reactor.

Accordingly, in one aspect, the invention provides a stacked assembly of plates, the stack having an inlet and an outlet for a first fluid and an inlet and an outlet for a second fluid, a first portion of the length of the assembly being formed of one or more first perforated plates, each first perforated plate being perforated to define a first series of slots spaced across the plate and a second series of slots spaced across the plate, each slot of the first series being positioned between a pair of slots of the second series, whereby the slots of the first series define first passageways through the first portion of the length for a first fluid and the slots of the second series define second passageways through the first portion of the length for a second fluid, the first series of passageways being connected to said inlet and outlet for the first fluid, a second portion of the length of the assembly being formed of one or more second perforated plates, each second perforated plate being perforated to define a first and a second series of slots corresponding to the slots of the first plate(s) so as to provide continuing passageways in line with the first and second passageways of the first portion, each slot of the second series opening at one of its two ends into a feeder slot extending across the second plate, the feeder slot(s) being connected to an inlet or an outlet for the second fluid.

In another aspect the invention provides a heat exchanger comprising a stacked assembly of plates as defined in the immediately preceding paragraph.

In a yet further aspect the invention provides a perforated plate for a heat exchanger, the plate being perforated to define a first series of slots spaced across the plate and a second series of slots spaced across the plate, each slot of the first series being positioned between a pair of slots of the second series, each slot of the second series opening at one of its two ends into a feeder slot extending across the second plate, the feeder slot thereby connecting those first ends together

If desired, each slot of the second series of a second plate may open at each of its ends into one of a pair of feeder slots.

In one embodiment the assembly has a third portion of its length formed at the other end of the first portion, the plate(s) of the third portion being of a similar construction to the plates of the second portion with the feeder slot(s) being connected to an outlet or an inlet accordingly for the second fluid. In a particularly preferred embodiment, the, or each, plate of the third portion is formed to have its feeder slot extending on the opposite side of the assembly to the feeder slots of the first portion, whereby the second fluid must cross the assembly from one side to the other between the second fluid inlet and outlet.

The first fluid is conveniently the fluid to contact the catalyst when the structure of the invention is to be used as a packed bed catalytic reactor and the catalyst will, therefore, be packed into the first series of passageways through

the assembly. The second fluid, correspondingly, will be a coolant or a source of heat, as required.

The plates may be of any suitable shape, e.g. they may be discs, i.e. they may be circular in plan, and the slots may be arcuate or linear. Preferably, however, the plates are square or rectangular and the slots preferably are linear.

In another preferred embodiment, the stacked assembly may comprise first and second length portions as described above, a baffle plate and then another set of first and second length portions, i.e. the baffle plate lies between a pair of adjacent first length portions and the end of each first length portion away from the baffle plate is in contact with a second length portion.

The baffle plate may, for example, contain a series of slots corresponding to and in line with the first series of passageways for the first fluid so that the first fluid has an uninterrupted flow through the assembly and a second series of staggered slots which partially interrupt flow through the second series of passageways and thereby cause some at least of the coolant or heating fluid to travel non-linearly between the two halves of the assembly divided by the baffle plate. Baffle plates may be placed at any position or frequency in the stack according to design and flow distribution requirements.

In another preferred embodiment of the invention, the assembly of plates includes at one or each end thereof a perforated closure plate. The closure plate may, for example, have a first series of slots corresponding to the first passageways, whereby the first fluid can flow uninterrupted through the closure plates, but no slots corresponding to the second passageways, whereby the

second fluid is diverted into the inlet and/or outlet provided into or out of the second plate(s).

Conveniently all the plates may be of the same external dimensions in plan so that they can be readily assembled together to provide the desired passageways through the assembly. The plates may conveniently all be of the same thickness, e.g. from 1 mm to 12 mm. However, this is not essential and it may be found advantageous in particular circumstances to use plates of different thickness in the assembly.

The plates may be brazed or bonded together to form the stack. For example, the plates may be of clad aluminium or of stainless steel. The required perforations may be cut, for example, by high pressure water jet or by etching, blanking or laser cutting. The perforated plates can then be vacuum brazed or bonded together and any required inlet and outlet connections and tanks can be welded to the bonded stacked assembly.

It will be appreciated that each perforated plate will have a solid peripheral region extending around its perimeter and that each slot will be surrounded by a solid region of plate except at the open ends of the second slots where they open into the feeder slot. Adjacent solid regions extending between adjacent pairs of first slots may, therefore, need to be connected together by one or more strengthening tie bars extending across an intervening second slot. One such a tie bar may conveniently be positioned towards the open end of the second slot.

Similarly, the feeder slot, which may extend along almost the entire length of one side of a rectangular plate, may be defined inside a solid edge portion along one edge of the plate. If it is desired to feed into the second fluid inlet from a side of the plate, then a gap must be provided in the solid edge portion for that purpose, thereby providing an inlet into the feeder slot. However, this may not be necessary if it is desired to feed into the feeder slot in the direction of the thickness of the plate rather than transversely to that direction. If a gap is provided in the solid edge portion, then one or more tie bars may be needed, preferably adjacent that gap to connect the solid edge portion to a solid region extending across the plate between an adjacent pair of slots.

Whether or not tie bars will be needed will be determined by the rigidity of the perforated plates and hence will be determined by their material and their thickness. It will be appreciated that in order to bond the stack together conveniently, there should be little or no undue movement of any solid regions of the plate out of the plane of the plate during handling.

Where one or more tie bars is necessary in the second plates, it will be necessary to utilise at least two different second plates. Although they may be essentially of the same slotted construction, they differ in the positioning of their tie bars so that when two such second plates are stacked together, although their feeder slots and first and second passageway slots respectively align with each other, their tie bars are offset from each other. By this means, fluid can flow over the tie bars whereas if the tie bars were located together, flow through the stack would be prevented.

Injection plates may be provided in the stack whereby one or more further fluids can be injected into the first fluid as it passes through the stack. A typical injection plate may be a modified first type of plate in which an injection channel is provided in the form of a groove extending only partially into the thickness of the plate. The groove may extend from an edge of the plate to pass adjacent the ends of the first slots that lie towards that edge of the plate and then branch grooves from the main groove may extend into each slot. Because the groove does not extend completely through the thickness of the plate it will be sealed by contact between that plate and solid regions of an adjacent plate in the stack.

In another embodiment, pressure equalisation means may be provided between the first passageways defined by the first series of slots. This may be particularly useful where the heat exchanger is to be used as a packed bed catalytic reactor and the catalyst is packed into those first passageways. By use of such pressure equalisation means, reaction quality across the whole of the reactor can be more consistent, thereby providing greater efficiency.

The pressure equalisation may be achieved by any convenient means. For example, the rows of slots of the first series may be joined together at their ends providing in effect a single continuous slot of serpentine form. Alternatively, venting may be provided between adjacent pairs of first slots. Such venting may conveniently be provided through arrays of tie bars, each array extending in spaced formation along the length of each second slot and each tie bar of the array running across its second slot from one first slot to an adjacent first slot. A venting channel may be etched partially or otherwise formed into the thickness of each tie bar whereby a portion of the fluid passing through a passageway

defined by one series of stacked first slots may vent through to a passageway defined by another series of stacked adjacent first slots.

Embodiments of the invention will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1 is a diagrammatic elevation of a packed bed catalytic reactor of the invention;

Figure 2 is a plan view of a first type of perforated plate for use in the reactor of Figure 1;

Figure 3 is a plan view of one second type of perforated plate for use in the reactor of Figure 1;

Figure 4 is a plan view of another second type of perforated plate for use in the reactor of Figure 1;

Figure 5 is a baffle plate for use in the reactor of Figure 1;

Figure 6 is a closure plate for use in the reactor of Figure 1;

Figure 7 is a view in the direction of arrow VII-VII of Figure 1;

Figure 8 is a view in the direction of arrow VIII-VIII of Figure 1;

Figure 9 is a plan view of a further type of plate for use in the invention;

Figure 9A is a section on line IX-IX of Figure 9;

Figure 9B is an enlarged view of area I of Figure 9;

Figure 10 is a diagrammatic elevation of an assembly of the invention comprising a plurality of stacks of plates with injection features;

Figure 11 is a plan view of a yet further type of plate for use in the invention;

Figure 12 is a plan view of a second type of perforated plate in which the slots of the first series are joined to form a continuous single slot;

Figure 13 is a plan view of a first type of perforated plate in which venting is provided between adjacent pairs of first slots;

Figure 14 is a section on line XIV-XIV of Figure 13;

Figure 15 is a plan view of another first type of perforated plate in which venting is provided between adjacent pairs of first slots;

Figure 16 is a plan view of another first type of perforated plate in which venting is provided between adjacent pairs of first slots;

Figure 17 is a plan view of an alternative first type of perforated plate for use in the invention;

Figure 18 is a plan view of a circular closure plate for use in a stack with a circular first type of plate;

Figure 19 is a plan view of a circular second type of plate;

Figure 20 is a plan view of a modified circular second type of plate;

Figure 21 is a plan view of a circular first type of plate;

Figure 22 is an injection plate for use in the stack with the plates of Figures 18 to 21;

Figure 23 is a perspective view of a packed bed catalytic reactor of the invention formed from plates of Figures 18 to 21;

Figure 24 is a plan view of another form of end closure plate;

Figure 25 is a diagrammatic representation showing the coolant, i.e. second fluid, flow paths through a reactor of the invention;

Figure 26 is a diagrammatic representation showing the flow paths for injected fluid through the reactor; and

Figure 27 is a plan view of a portion of another second type of plate of the invention.

In Figure 1 a packed bed catalytic reactor is formed of a stacked assembly 10 of perforated plates. The individual plates are described in greater detail below with reference to Figures 2 to 6.

The stack has an inlet end 12 and an outlet end 14 for flow therethrough of a first fluid which is to pass in the direction of arrow A. (As described below with reference to Figures 7 and 8, the passageways through which the first fluid flows are packed with a catalyst.).

At the lower outlet end of the stack is a mesh cover 16 to retain the catalyst whilst allowing fluid through flow. Immediately above mesh 16 is a closure plate 18, which is described in more detail below with reference to Figure 6.

Stacked in succession above closure plate 16 are, firstly, a second type of perforated plate 20, a modified second type of perforated plate 22 and another second type of perforated plate 20A, identical to plate 20. Plates 20, 20A and 20 form the aforesaid second portion of the length of the assembled stack and provide an inlet 24 for a second fluid, e.g. a coolant, into the stack. Plates 20 and 22 are described in more detail below with reference to Figures 3 and 4 respectively.

Immediately above plate 20A are four identical first type of perforated plates 26, forming the aforesaid first portion of the length of the assembled stack. A plate 26 is described in more detail below with reference to Figure 2.

Above plates 26 is a baffle plate 28, described in more detail below with reference to Figure 5.

Above baffle plate 28 is a further assembly of five first type of perforated plates 26A. Plates 26A are identical to plates 26.

Above plates 26A is a further assembly of another second type of perforated plate 30, a modified second type of perforated plate 32 and another second type of perforated plate 30A, identical to plate 30. Plates 30, 32 and 30A provide an outlet 34 for the second fluid from the stack.

Plates 20 and 30 are identical in construction except that they are rotated through 180° in the plane of the plates relative to each other. Plates 22 and 32 are also identical except that they are rotated through 180° with respect to each other.

The first type of perforated plates 26 are as illustrated in Figure 2. Each plate is rectangular in plan and has a first series of linear slots 36 through its thickness. Each slot 36 extends from adjacent one edge 38 to adjacent an opposite edge 40 leaving unperforated margins 38' and 40' respectively inside those edges. The series of slots 36 extends across the plate between opposite edges 42 and 44. Each plate also has a second series of linear slots 46 through its thickness. Each slot 46 extends between edges 38 and 40 of the plate inside margins 38' and 40' and the series of slots 46 also extends across the plate between edges 42 and 44.

As shown, each first slot 36 lies between a pair of second slots 46 and the slots nearest edges 42 and 44 are both second slots 46, which lie inside margins 42' and 44' respectively at those edges. Thus the plate has a continuous solid margin 38', 42', 40', 44' around its periphery and margins 38' and 40' are also joined together by lands 48 lying between adjacent pairs of slots.

The slots 36 and the slots 46 of plates 26 form respective passageways for the first fluid and the second fluid when the plates are stacked together.

One second type of plate 20 is shown in Figure 3. Plate 20 is also rectangular in plan and has a first series of linear slots 36A identical to the slots 36 in plate 26. Plate 20 also has a second series of slots 46A corresponding in size and location to slots 46 of plate 26. Slots 36A and 46A lie inside a solid peripheral margin 38A', 42A', 40A', 44A' between edges 38A, 42A, 40A and 44A of the plate. However, although margins 40A' and 40A and 44A' and 44A are identical, margins 38A' and 42A' of plate 20 are different from margins 38A and 42 of plate 26.

Margin 38A' of plate 20 is formed as a depending leg from margin 44A' and a feeder slot 50 is formed in the plate to extend parallel to edge 38A and between margin 38A' and the ends of slots 36A and 46A. Depending leg or margin 38A' is tied to the lowermost land 48A between the slots 46A and 36A nearest to edge 42A by a tie bar 52.

Each slot 46A would open into feeder slot 50 except that a tie bar 54 is formed between each adjacent pair of lands 48A between adjacent slots to maintain adequate rigidity of the plate. The lowermost land 48A adjacent

margin 42A' is also joined to margin 42A' by a tie bar 56 and the uppermost land 48A is similarly joined to margin 44A' by a tie bar 58. As shown, all the tie bars are positioned across their respective slots 46A towards the end of their slot nearest to feeder slot 50.

Margin 42A' is provided with a gap 60 adjacent margin 38A' whereby an inlet 62 is formed into the stack for a second fluid. (It will be appreciated that gap 60 could be positioned anywhere along the edges 38A or 42A as its purpose is to feed into feeder slot 50 and the lowermost slot 46A.).

It will also be appreciated that an assembly of one or more plates such as plate 20 in direct contact with one or more plates such as plate 26 would prevent flow of second fluid into the feeder slot 50 and so prevent flow into slots 46A and thence slots 46. A modified type of second plate, perforated as shown in Figure 4, is therefore utilised.

In Figure 4 plate 22 is similar to plate 20 in that it has identical series of slots 36B corresponding to slots 36A and slots 46B corresponding to slots 46A. It also has a feeder slot 50B adjacent one edge 38B and a gap 60B in edge 42B to form an inlet 62B. Plate 22 is also provided with tie bars for the same reason as in plate 20. Thus tie bars 54B are formed one in each slot 46B but spaced further from feeder slot 50B then tie bars 54 are from feeder slot 50. Similarly a tie bar 56B extends across lowermost slot 46B to join it to peripheral margin 42B' of the plate 22 and a tie 58B extends across uppermost slot 46B to join it to peripheral margin 44B'. Tie bars 56B and 58B are postponed further from inlet 62B and feeder slot 50B respectively than are their counterparts in plate 20. Finally margin 38B' is joined to a land 48B by a tie bar 52B. This land 48B is

the second such land in from the edge 42B' of the plate whereas in plate 20 tie bar 52 joins leg 38A to the first land 48A adjacent edge 42A.

Thus all the respective tie bars in plates 20 and 22 are offset and, as described in more detail below with reference to Figures 7 and 8, this enables through flow of the second fluid through the stack.

Baffle plate 28 is shown in Figure 5. Plate 28 has a first series of slots 66 of size and position corresponding to slots 36 of plate 26, 36A of plate 20 and 36B of plate 22. Thus flow of the first fluid through these plates in the stack is unimpeded. However, instead of a second series of slots corresponding to slots 46, 46A and 46B of plates 26, 20 and 22, baffle plate 28 has two series of slots 68 and 70. Each slot 68 or 70 is approximately half of the length of each slot 46, 46A or 46B. Slots 68 extend from a peripheral solid margin 72 at the right hand side of the plate as shown to the centre of plate and slots 70 extend from a peripheral solid margin 74 at the left hand side of the plate to the centre. Slots 68 and 70 are staggered across the plate from one edge 76 to the opposite edge 78 whereby each slot 66 has a slot 68 extending from one of its ends for half the length of one of its longer sides and another slot 70 extending from its other end for half of the length of the other of its longer sides. Thus the channels formed in the stack by the successive slots 46 in plates 26 are alternately blocked for half their length and the second fluid flow is forced to take a part-sinuous path to travel from one side of the baffle plate to the other. This is illustrated by the double-headed arrows in Figure 1.

The closure plate 18 used at each end of the stack is shown in Figure 6. It has a first series of slots 86 corresponding to slots 36, 36A, 36B and 66 of plates

26, 20 22 and 28 respectively so that flow of first fluid through the stack is not interrupted. However, plate 18 has solid unperforated lands 88 between slots 86 and has solid, unperforated margins 90 all around its periphery. The second fluid flow channels formed by slots 46, 46A and 46B are, therefore, closed off at each end of the stack and the second fluid flows into the stack via inlet 24 (formed by gaps 60 and 60B and inlet portions 62 and 62B of two plates 20 and one plate 22) and flows out of the stack via a similarly firmed outlet 34 (see Figure 1).

In Figure 7, plate 20A can be seen. This lies directly above plate 22 and then plate 20, which is identical to plate 20A. (The same reference numerals are, therefore, used for the constituent parts of the plates 20 and 20A.).

The channels formed by the first series of slots (36A in plate 20A) are packed with catalytic material 92 to promote reaction of a first fluid passing through those channels. The second series of slots have staggered tie bars 54 and 54B from plates 20A and 22 respectively (each with a second tie bar 54 in plate 20 hidden below and spaced from the shown tie bar 54), staggered tie bars 56 and 56B (again with another hidden, spaced tie bar 56) and staggered tie bars 52 and 52B (again with another hidden tie bar 52).

The second fluid flows in at inlet 60 (and 60B and a further 60 in the lower plate 20) and because of the staggering of the tie bars can flow past the tie bars as indicated by the arrows to pass along the feeder slot 50 and into each channel formed by slots 46A. The second fluid can, thereby, flow through he stack in good heat exchange contact with the first fluid which is flowing axially in the opposite direction.

Figure 8 shows the outlet 34 arrangement at the opposite end of the stack to Figure 7. Plate 30A is identical to plate 20A but is positioned in the stack rotated through 180° relative to plate 20A. Similarly, immediately below plate 30A is a plate 32 identical to plate 22 but rotated through 180° and immediately below plate 32 is another plate 30, identical to plate 20 but also rotated through 180°. (The constituents of plate 30A being identical to those of plates 20 and 20A are marked with the same reference numerals.).

Flow of second fluid is again indicated by the arrows and passes from the channels which include slots 46A and the feeder slot 50, via the tie bars to outlet 34.

In Figure 9 is shown a plate 100 which enables injection of fluid e.g. air or reactant, into the first fluid in the first passageways.

Plate 100 has a series of first slots 102 corresponding to slots 36, 36A and 36B in the above-described plates 26, 20 and 22 respectively. Thus when positioned in a stack of plates such as plates 26, 20 and 22, plate 100 offers no obstruction to through flow of first fluid. (Catalyst may, of course, be packed into the passageways formed by slots 102, 36, 36A and 36B.).

Each first slot 102 lies between a pair of injection grooves 104 and each groove 104 opens into a feeder groove 106 into which fluid can be injected via a groove inlet 108. The grooves extend only partially, e.g. halfway, into the thickness of the plate so that they are closed off by the remaining thickness of the plate from the second channels in the next plate in a stack.

Lands 110 between adjacent slots 102 and grooves 104 are provided with spaced grooves 112 which may similarly be, for example, of depth equal to half the thickness of the lands, as shown in Figure 9A. Injected fluid can, therefore, travel from inlet 108 via feeder slot 106 into each groove 104 and then via grooves 112 into each slot 102 as indicated by the arrows.

It will be appreciated that plate 100 can only be used next to an entry or exit region of a stack as an end plate having solid closure regions corresponding to and covering grooves 104 and 112 is needed to contain the injected fluid in the grooves.

In order to obtain uniform distribution of injected fluid in all the grooves 104, it is necessary to provide a form of restriction into the grooves nearest to the inlet 108. One form of restriction is shown in Figure 9B and takes the form of a local restriction or narrowing of the groove at 104A. The nearer the groove is to the inlet 108, the greater is the restriction so that the groove furthest from the inlet may have no such restriction. In an alternative embodiment the injection grooves themselves may be wider, the further they are from the inlet.

In Figure 10 is shown a catalytic reactor or heat exchanger assembly comprising four stacks of plates, i.e. stacks 121, 122, 123 and 124. The ends of each stack have a closure plate 125 e.g. of the type shown in Figure 6.

First fluid flows through the stack from an inlet end 126 to an outlet end 127.

Each stack 121 to 124 comprises an assembly of first and second type plates as described above between its end closure plates and each stack has an inlet 128 and an outlet 129 for second fluid.

Thus second fluid, e.g. coolant, can enter at the lowest inlet 128 and leave at the lowest outlet 129, thereby cooling the lowest stack 124. Separate coolant flows through inlets 128 and outlets 129 to each of the other stacks 123, 122 and 121 ensure that a long heat exchanger still has adequate cooling (or heating if desired) over its whole length.

Centrally positioned in each stack 121, 122, 123 and 124, lies an injection plate of the type described below with reference to Figure 11. Each such injection plate has an inlet 240 through which injected fluid may be mixed with the first fluid flowing through the assembly.

Adjacent the inlet end of each stack 121, 122, 123 and 124, lies an injection plate of the type described above with reference to Figure 9. These plates have an inlet 138, which also enables injection of a fluid into the first fluid flowing through the assembly.

In Figure 11 is shown a form of plate 200 which enables injection of fluid into the first fluid in the first passageways at any position along the stack, e.g. as indicated above with reference to inlets 240 in Figure 10.

Plate 200 has a first series of slots 202 corresponding to slots 102 of Figure 9. Thus when positioned in a stack of plates such as plates 26, 20 and 22, plate 200 offers no obstruction to through flow of first fluid. (Again, catalyst

may be packed into passageways formed by the stacked slots 202, 36, 36A and 36B.).

Each first slot lies between a pair of second slots 204 which in a stack form passageways with corresponding second slots through which second fluid may pass. Each second slot 204 has a plurality of tie bars 206 spaced along its length.

An inlet 208 for injected fluid is provided at one edge 200A of the plate. This leads to an injection feeder groove 210 extending parallel to the edge 200A. Feeder groove 210 has a number of branches 212, one branch corresponding to and leading into each first slot 202 whereby injection fluid can be introduced into the first slots. Again it may be desirable to provide restrictions on the feeder branches in a similar manner as described above with reference to Figure 9 so as to provide uniform distribution of injected fluid. As with Figure 9, the grooves may be of depth equal to, say, half of the thickness of the plate. It will be appreciated that in a stack these grooves will be closed to contain the injected fluid by the corresponding solid border region of the adjacent plate.

It will also be preferable to use plates 200 in pairs rotated through 180° with respect to each other so that improved distribution is obtained by means of injection from opposite sides of the stack.

In Figure 12 a second perforated plate 250 has a series of longitudinally-extending first slots 252 joined into a continuous single slot by curved perforation portions 253 joining the ends of adjacent slots. Of course, these joining perforations need not be curved but may be linear and thereby provide a

pair of right-angled bends between adjacent slots. Each longitudinal slot portion 252 lies between a pair of second slots 254, each second slot being sub-divided into a plurality of sub-slots by tie bars 258. Feeder slots 260, 262 for second slots 252 are positioned one adjacent each opposed edge 264, 266 of the plate to provide access into the second fluid passageways formed by the second slots in a stack of the plates. (As explained above, these second perforated plates are stacked in pairs with the tie bars of one plate offset with respect to those of the other plate.).

The provision of slots 252 as a continuous slot encourages equalisation to take place of any pressure differences in the first fluid flowing through the stack.

In Figures 13 and 14 a first perforated plate 270 has a first series of slots 272 and a second series of slots 274. Each slot 274 is sub-divided into a number of smaller slots by tie bars 278. In each second series of slots that lies between adjacent first slots, each tie bar has been etched partway through its thickness to form a vent passage 280 extending between adjacent first slots 272. Vent passages 280 provide another means whereby first fluid pressure in the first passageways across a stack of plates of the invention may be equalised and the provision of vent passages throughout the stack enables very localised pressure differentials to be equalised. (It will be appreciated that a tie bar to be etched in this manner may need to be of greater width than a corresponding tie bar that is not required to be etched.).

In Figures 15 and 16 is shown a pair of first perforated plates 290 and 290A that co-operate together to provide vent channels or passages between adjacent pairs of first slots. Each plate has a first series of slots 292, 292A and

second slots 294, 294A, the plates being identical in this respect. Each second series of slots is sub-divided into a number of smaller slots by tie bars 298, 298A, the tie bars being identically positioned in both plates.

In each second series of slots that lies between adjacent first slots, the tie bars in each plate have each had a recess 296, 296A cut completely through their thickness. Each recess opens at one end into a slot 292 or 292A and extends along the majority of the length of its tie bar but is closed off at its other end from the next adjacent slot 292, 292A by an unremoved land portion 297, 297A respectively.

The tie bars along each second series of slots alternately have their open and closed ends of their recesses facing into the first slots.

The open and closed ends of the tie bars in plate 290 are the opposite way round to those of plate 290A. Hence when the plates are stacked together a passageway is formed in each superimposed pair of tie bars whereby pressure equalisation of first fluid passing along the first series of passageways can take place between adjacent pairs of first passageways. Hence even very localised pressure differentials are again readily equalised.

The recesses may be etched or cut by other means, e.g. by machining, water jet or laser jet.

In Figure 17 is shown an alternative form of first type of plate 300. Plate 300 has first slots 302 for first fluid and second slots 304 for second fluid. Slots 302 have tie bars 306 and slots 304 have tie bars 308. It will be noted that tie

bars 306 divide slots 302 into portions spaced uniformly along each slot whereas the positions of tie bars 308 are staggered with respect to the ends of their slots, i.e. the tie bar nearest to one end of its slot is nearer to that end than the tie bar at the opposite end of that slot is to that opposite end.

Thus, if the plates of a pair of plates 300 are rotated through 180° with respect to each other in a stack of plates, tie bars 306 of the pair of plates will be aligned in correspondence with each other but tie bars 308 will be staggered. This staggering effect can be used to create extra turbulence in the second fluid as it flows through the stack and thereby obtain a greater heat exchange effect. For example, a pair of plates 300 could be stacked one on either side of a similar third plate but which third plate has a completely uniform distribution of tie bars. In contrast, the correspondence of tie bars 306, which can be repeated in all of the plates through the stack, divides the first slots into individual cells 310 into which catalyst can be packed. This structure is then particularly useful for high pressure applications wherein, for example, a gas can be passed through the catalyst in the cells of the stack at relatively high pressure.

In Figure 18 a circular end closure plate 400 has a solid annular outer peripheral region 401 with eight equi-spaced bolt holes 409 and four lugs 402, 403, 404, 405 extending from its outer periphery. Lugs 403 and 405, which are diametrically opposed across the plate, contain holes 406 and 407 respectively for the introduction of injection fluids, which may be the same or different, into the first fluid passing through the stack. Lug 404, which is diametrically opposed across the plate to unperforated lug 402, has a hole 408 for the entry or exit of coolant to or from the stacks.

Disposed centrally beyond region 401 is a series of linear slots 412 separated by lands 413, i.e. the plate has a first series of slots for passage of first fluid through the stack but no second series of slots. Second fluid, therefore, cannot pass through the end plate 400 but leaves or enters via second plates 500 and 500A as described below with reference to Figures 19 and 20.

In Figures 19 and 20 are shown circular plates 500 and 500A, which are to be stacked together adjacent to closure plate 400 to provide entry or exit for coolant. Plates 500 and 500A are identical except in respect of their feeder slot and tie bar constructions, which will be explained below. Each plate has four lugs 502, 502A; 503, 503A; 504, 504A; and 505, 505A respectively extending from its perimeters 509, 509A corresponding to lugs 402 to 405 of plate 400. The lugs on plates 500, 500A are longer than those on plate 400 (but the overall diameters defined by the outer extremities of the lugs are the same.). The radius of the plates to their perimeters 509, 509A is less than the radial extent of plate 400 to the innermost periphery of each bolt hole 409. Plates 500, 500A have a solid annular region 501, 501A inside perimeter 509, 509A and a central region comprising two series of slots. The first series of slots, 512, 512A, correspond to slots 412 of plate 400. A second series of slots 514, 514A extends between adjacent slots 512, 512A.

Slots 514, 514A, are each sub-divided by tie bars 513, 513A into a linear row of sub-slots but it will be noted that the tie bars 513 are offset along their respective slots compared to tie bars 513A. Each slot 514, 514A opens at one end into a feeder slot 515, 515A. Again it will be seen that feeder slots 515, 515A are each formed as a series of sub-slots by means of tie bars 516, 516A It will also be seen that tie bars 516 and 516A are offset with respect to each other.

Lugs 503, 503A and 505, 505A each contains a hole 506, 506A; 507, 507A respectively positioned to coincide with holes 406, 407 of plate 400 whereby injected fluid may pass through the lugs of the adjacent plates in the stack.

Lugs 502, 502A are unperforated but lugs 504, 504A contain a feeder inlet or outlet 508, 508A, which allows second fluid, i.e. coolant, to flow into or out of the feeder slots 515, 515A and from there into slots 514, 514A. The coolant enters 508, 508A via hole 408 in plate 400 or leaves from 508, 508A to exit through hole 408.

Because tie bars 513, 513A and 516, 516A are staggered coolant can flow under and over the cross bars of adjacent plates 500, 500A to extend completely along slots 514, 514A.

Figure 21 shows a first type of plate 600 to be used in a stack with the plates of Figures 4, 5 and 6. This has an outer perimeter 609 of radius corresponding to perimeter 509, 509A and four lugs 602, 603, 604, 605 extending from its perimeter. These lugs are of size and position corresponding to lugs 502, 502A; 503, 503A; 504, 504A; and 505, 505A.

Lugs 602 and 604 are unperforated. Lugs 603 and 605 have holes 606 and 607 to allow continued passage of injection fluid.

Centrally beyond solid annular region 601 of the plate lie two series of slots 612 and 614 corresponding to slots 512, 512A and 514, 514A respectively.

Slots 614 are subdivided by tie bars 616. A plurality of adjacent plates 600 may be used in the stack.

Figure 22 shows an injection plate 700 which can be positioned at a desired height in the stack to inject another fluid into the first fluid passing through the passageways formed by the slots 612, 512, 512A and 412. The plate has an outer periphery 709 of radius corresponding to perimeters 509, 509A and 609 and four lugs 702, 703, 704, 705 extending from its perimeter. These lugs again are of size and position corresponding to the lugs of plates 500, 500A and 600. Lugs 702 and 704 are unperforated. Lug 703 has a hole 706 to allow one injected fluid to pass through plate 700 to continue to a different height in the stack before injection into the first fluid. Lug 705 contains an injection groove 707. This extends only part way through the thickness of the plate and leads towards the centre of the plate where it meets an arcuate feeder groove 708 which has branches 710 each leading into one end of one of a first series of slots 712. The feeder groove and its branches also extend only partially through the thickness of the plate whereby injection fluid is contained to travel through the groove into slots 712 by being closed above by the solid region of the adjacent plate above plate 700 in the stack. The plate has a second series of slots 714 with tie bars 716 and the first and second series of slots line up through the stack with their counterparts in the other plates.

A plate similar to plate 700 but with lug 707 ungrooved and the grooved injection arrangement provided in lug 703 in place of hole 706 can be used further down the stack to introduce another injected fluid, or more of the same injected fluid.

In Figure 23 a packed bed catalytic reactor 800 is made up as a stack of plates of the types shown in Figures 18 to 22. It has an upper end plate 400 and a similar lower end plate 400. Stacked between those plates, but not individually visible, are firstly an upper pair of second plates 500, 500A and then a stack of first plates 600. A pair of injection plates 700 are positioned, one each at a different height in the stack of first plates. Beneath the lowermost first plate is another pair of second plates 500, 500A and then the lower plate 400. The lugs of the plates combine to form four columns 802, 803, 804 and 805 extending longitudinally on the exterior of the stack. Column 802 is formed from lugs 402, 502, 502A 602 and 702 and has no flow channel within it. Column 803 is formed from lugs 403, 503, 503A, 603 and 703 and has an injection flow channel provided by holes 406, 506, 506A and 606 leading to an injection feeder groove 707 in a plate 700 as described above. Column 804 is formed from lugs 404, 504, 504A, 604 and 704 and has a second fluid, i.e. coolant, feeder channel provided by holes 408 and channels 508 and 508A. Column 805 is formed from lugs 405, 505, 505A, 605 and 705 and has an injection flow channel provided by holes 407, 507, 507A, 607, 707 leading to another injection groove in another plate 700.

The assembly can be bolted into pipe/flange assemblies using long bolts passing through corresponding pairs of holes 409 in the two end plates or by conventional nuts and bolts.

First fluid flows unimpeded through the reactor in the direction of arrow A through the passageways formed by the first series of slots. These passageways may be packed with catalyst.

Coolant flows in the opposite direction as indicated by arrow B through the second series of passageways provided by the second series of slots.

Injected fluid flows into the stack as indicated by arrows C and D and leaves with the first fluid flow – see arrow A at the lower end of the stack.

It will be appreciated that with appropriately positioned entry and exit plates, i.e. with appropriately positioned coolant feeder channels, the coolant flow may enter in column 804 and leave from column 802, thereby crossing the stack for greater cooling effect. It will also be appreciated that such an arrangement, rather than the use of baffle plates, is necessary when the second slots are subdivided by tie bars and the second plates are used in pairs with their tie bars offset from each other.

Figure 24 shows an alternative end plate 920 having six injection ports. As with plate 401, this plate 920 has a first series of slots 922 but no second series of slots. It has eight equi-spaced lugs 923 to 930 which provide six injection inlets 933 to 938 for up to six different injection fluids and an inlet or an outlet, 931 for cooling fluid. The eighth lug is unperforated.

Plate 920 when stacked with a suitable series of first, second and injection plates provides a reactor in which the flows are as indicated in Figures 25 and 26.

In Figure 25 stack 900 is made up of an end plate 920 at each end, a pair of second plates 950, 950A adjacent each end plate and a stack of first plates 960. Interspersed amongst the first plates (and shown in Figure 12) are six

injection plates. First fluid flows directly through the stack as indicated by arrow A. Coolant enters at the lower end of the stack and flows upwardly to leave from the upper plate 920 at the opposite side to which it entered as indicated by arrow B.

In Figure 26 the first fluid flow is shown as before but the coolant flow is omitted for clarity. A stack of first plates 960 includes six injection plates 970 at different levels, three injection inlets being diametrically opposed across the stack from the other three. The injection flows are indicated by arrows C and D. End plates 920A and 920B differ in that upper plate 920B has holes in two of its lugs for the two injected fluids whereas the corresponding lugs in plate 920A are unperforated.

Where multi-injection channels are used, the injection of fluids can be controlled, e.g. by a microprocessor, whereby controlled additions or "doses" of a number of different fluids may be made into the process fluid, i.e. first fluid, on a programmed cycle. For example, at each injection point, the connection to the source of fluid to be injected may be via a solenoid valve which can be opened to allow injection for a predetermined time by the microprocessor. Improved chemical reaction processes may thereby be achieved

In a yet further embodiment where circular plan plates are used, the length of the slots of the first and second series may be maintained constant rather than decreasing from the centre of the plate to the outer slots. This arrangement can increase the effective catalyst to volume ratio in the stack, e.g. by up to 15%.

In another embodiment the slots of the first series may be subdivided by tie bars so that all or the majority of the sub-divided slots are of the same length. Cooling channels provided by the second series of slots can be arranged to turn to pass through the tie bars so that the cooling effect in the stack can be spread around the sub-divided first slots to give even greater uniformity. An arrangement to achieve a similar effect is shown in Figure 27 Here plate 980 has a first series of slots 982 which are spaced in rows across the plate, each row except the diametrically outermost rows containing two separate slots separated by a land region 983. Each row of first slots lies between a row of second slots 984. The second slots are shown with and without tie bars 985 to indicate the variety possible. Each second slot opens into a feeder slot 986 which is fed from an inlet (not shown) in the manner previously described.

The second slots, except for the diametrically outermost second slots, communicate into a further slot 988 which runs transversely to the other slots along the central land region 983 thereby enabling second fluid (coolant) to be better distributed around the first fluid passageways defined in a stack by the pairs of first slots. (Each pair of first slots may, of course, be considered to be a subdivided slot.). The flow of second fluid is indicated by the arrows.

An arrangement in which the catalyst channels in the stack are of the same size and cross-section also gives more uniform packing of the catalyst in the reactor which can improve the quality and reproducibility of the process.

It will be appreciated that the invention is not limited to the embodiments shown. The slots may be of different length, shape and sequences, although it will be appreciate that the passing of second fluid between the first fluid

channels is important for good heat exchange. Thus, for example, the slots need not extend continuously from adjacent one edge of a plate to adjacent the opposite edge. The inlets and outlets for the second fluid need not be positioned near to a corner of the plate.

As indicated above, where tie bars are used across second slots, the tie bars need to be staggered, i.e. offset, from each other in at least two adjacent second plates to allow flow to distribute completely across the second slots immediately after a second fluid inlet and immediately prior to a second fluid outlet. However, if tie bars are used across second slots in plates at other positions in the stack, they may be aligned or offset with respect to those of an adjacent plate. Where they are aligned, i.e. they stack together, pressure drop may be reduced. Where they are offset turbulence may be increased resulting, for example, in greater cooling effect.

It will also be appreciated that where a baffle plate is used, it will be advantageous that the plate or plates immediately downstream of the baffle should not have tie bars across the second slots unless they are staggered from one plate to the next. Otherwise, distribution of the second fluid across the second slots downstream of the baffle plate may be hindered or prevented.

CLAIMS

1. A stacked assembly of plates, the stack having an inlet (12) and an outlet (14) for a first fluid and an inlet (24) and an outlet (34) for a second fluid, characterised in that a first portion of the length of the assembly is formed of one or more first perforated plates (26), each first perforated plate being perforated to define a first series of slots (36) spaced across the plate and a second series of slots (46) is spaced across the plate, each slot (36) of the first series being positioned between a pair of slots (46) of the second series, whereby the slots of the first series define first passageways through the first portion of the length for a first fluid and the slots of the second series define second passageways through the first portion of the length for a second fluid, the first series of passageways being connected to said inlet (12) and outlet (14) for the first fluid, a second portion of the length of the assembly being formed of one or more second perforated plates (20, 22, 20A), each second perforated plate being perforated to define a first (36A, 36B) and a second (46A, 46B) series of slots corresponding to the slots of the first plate(s) so as to provide continuing passageways in line with the first and second passageways of the first portion, each slot (46A, 46B) of the second series opening at one of its two ends into a feeder slot (50, 50B) extending across the second plate, the feeder slot(s) being connected to an inlet (24) or an outlet (34) for the second fluid.

2. A stacked assembly according to Claim 1, characterised in that a third portion of the length of the assembly at the opposite end of the first portion to the second portion is formed of one or more plates (30, 32, 30A) of similar

construction to the plates of the second portion with the feeder slot(s) being connected to an outlet (34) or an inlet (24) accordingly for the second fluid.

3. A stacked assembly according to Claim 2, characterised in that the or each plate (30, 32, 30A) of the third portion is formed to have its feeder slot (50, 50B) extending in the opposite side of the assembly to the feeder slots (50, 50B) of the first portion, whereby the second fluid must cross the assembly from one side to the other between the second fluid inlet (24) and outlet (34).

4. A stacked assembly according to Claim 1, 2 or 3, characterised in that the first series of passageways is packed with a catalyst (92).

5. A stacked assembly according to any preceding claim, characterised in that the plates (20, 26, 22) are square or rectangular in plan and the slots (36, 46, 36A, 46A, 36B, 46B) are linear.

6. A stacked assembly according to any preceding claim, characterised in that it comprises along the stack a second length portion (20, 22, 20A), a first length portion (26), a baffle plate (28), a further first length portion (26A) and then a further second length portion (30, 32, 30A).

7. A stacked assembly according to Claim 6, characterised in that the baffle plate (28) comprises a series of slots (66) corresponding to and in line with the first series of passageways for the first fluid so that the first fluid has an uninterrupted flow through the assembly and a second series of staggered slots (68, 70) which partially interrupt flow through the second series of passageways

whereby some at least of the second fluid must travel non-linearly between the two halves of the assembly divided by the baffle plate.

8. A stacked assembly according to any preceding claim, characterised in that it includes at one or each end thereof a perforated closure plate (18).

9. A stacked assembly according to Claim 8, characterised in that the perforated closure plate (18) has a first series of slots (86) corresponding to the first passageways, whereby the first fluid can flow uninterrupted through the closure plate, but no slot corresponding to the second passageways, whereby the second fluid is diverted into the inlet (24) and/or outlet (34) provided in the second plate(s).

10. A stacked assembly according to any preceding claim, characterised in that it includes a plate (100) having a series of slots (102) corresponding to the first series of slots (36), wherein each slot (102) lies between a pair of injection grooves (104), the injection grooves (104) opening into a feeder groove (106) connected to an injection inlet (108), and the grooves (104) giving access into the slots at a plurality of positions (112) along each slot (102), whereby fluid may be injected into each slot (102), the plate (100) being positioned next to a plate having solid closure regions corresponding to and covering the grooves (104, 106, 108, 112).

11. A stacked assembly according to Claim 10, characterised in that restrictions (104A) are provided in some of the grooves (104), the restriction (104A) being greater the nearer the groove is to the injection inlet (108).

12. A stacked assembly according to any one of Claims 1 to 9, characterised in that it includes a modified first plate (200) in which one end of each first slot (202) is connected (212) to a feeder groove (210) extending across the plate, the feeder groove (210) being connected to an injection inlet (208).

13. A stacked assembly according to Claim 12, characterised in that it includes a pair of identical modified first plates (200) stacked together but rotated through 180° with respect to each other.

14. A stacked assembly according to any one of Claims 10 to 13, characterised in that the grooves (104, 106, 108, 112, 208, 210, 212) are of depth equal to about half the thickness of their respective plates (100, 200).

15. A stacked assembly according to any preceding claim, characterised in that all the plates are of the same external dimensions.

16. A stacked assembly according to any preceding claim, characterised in that the plates are from 1 mm to 12 mm in thickness.

17. A stacked assembly according to any preceding claim, characterised in that adjacent solid regions of a plate extending between adjacent pairs of first slots are connected together by one or more strengthening tie bars (54, 54B, 206, 258, 278, 298, 308) extending across an intervening second slot (46A, 46B, 204, 254, 274, 294, 304).

18. A stacked assembly according to any one of Claims 5 to 17, characterised in that the feeder slots (50, 50B) extend almost the entire length of one side

(38A, 38B) of their respective plates (20, 22) and are defined inside a solid edge portion (38A', 38B') at that side of the plate.

19. A stacked assembly according to Claim 18, characterised in that the second fluid is fed into the feeder slot (50, 50B) of a second plate (20, 22) through a gap (60, 60B) in a solid edge portion of the plate (42A', 42B') and a tie bar (56, 56B) is provided adjacent the gap to connect the solid edge portion to a solid region extending across the plate between an adjacent pair of slots (36A, 46A; 36B, 46B).

20. A stacked assembly according to Claim 19, characterised in that it comprises one or more adjacent pairs of second plates (20, 22), the plates of the pair having essentially the same slotted construction whereby their feeder slots (50, 50B) and first and second passageways are in alignment but their tie bars (56, 56B) are offset.

21. A stacked assembly according to any preceding claim, characterised in that in at least some of the plates (250, 270, 290, 290A) pressure equalisation means are provided between the first passageways defined by the first series of slots (252, 272, 292, 292A) in each of those plates.

22. A stacked assembly according to Claim 21, characterised in that the rows of slots (252) of the first series are joined together at their ends (253).

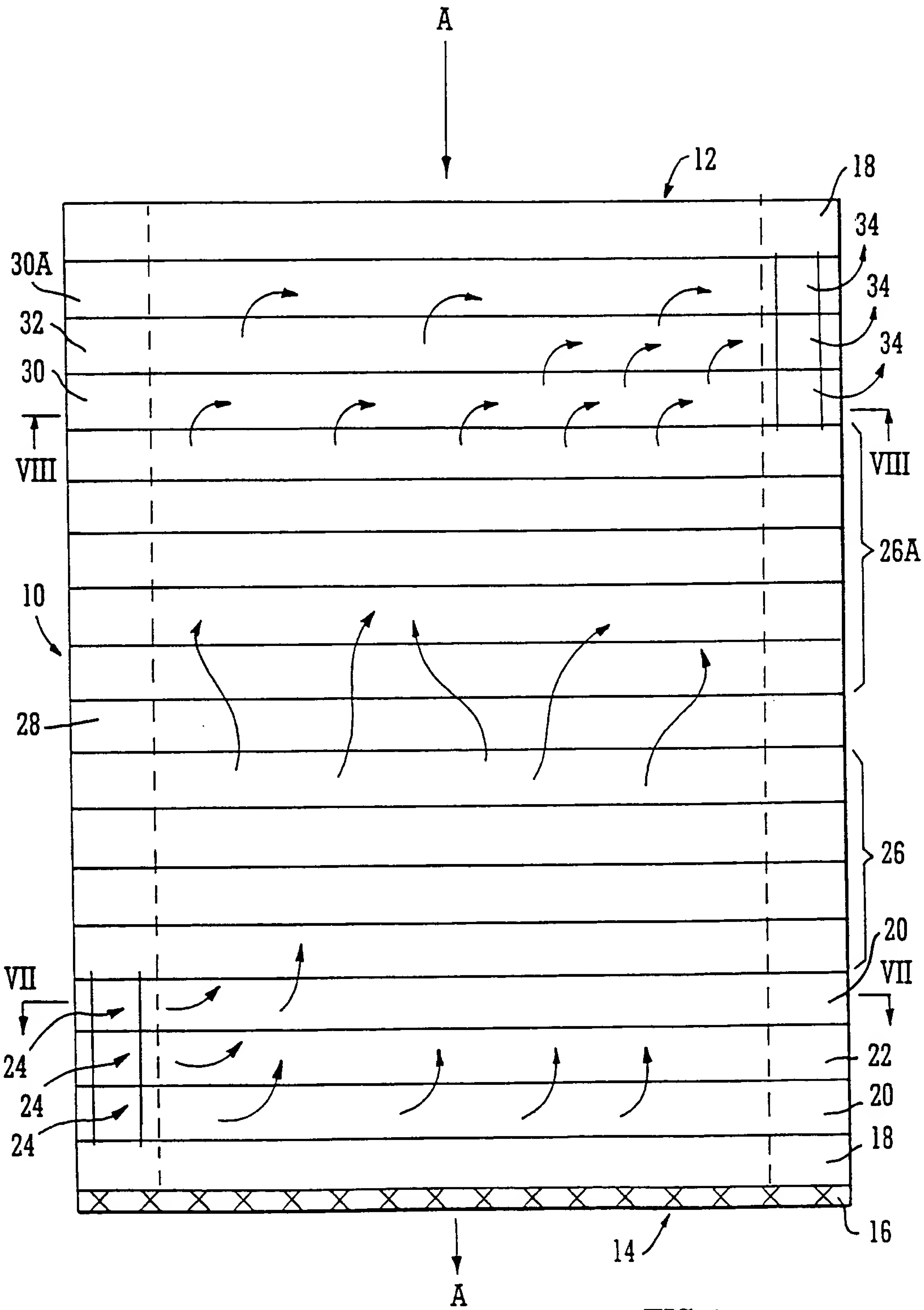
23. A stacked assembly according to Claim 21, characterised in that venting is provided through venting channels (280, 296, 296A) in tie bars (278, 298, 298A) spaced along the length of each second slot (274, 294, 294A), each tie bar

running across its second slot from one first slot (274, 292, 292A) to an adjacent first slot (272, 292, 292A) and having its venting channel formed partially through its thickness.

24. A stacked assembly according to any preceding claim, characterised in that the plates have one or more holes (328, 330) in a margin (332, 334) outside the slots (326), the holes aligning in the stack (320) to provide one or more passages (336, 338) through which a reactant may be injected into the stack, the passages connecting to first passageways through the stack at different levels in the stack.

25. A heat exchanger, characterised in that it comprises a stacked assembly (103, 320) of plates according to any one of the preceding claims.

26. A perforated plate for a heat exchanger, characterised in that the plate (20, 22) is perforated to define a first series of slots (36A, 36B) spaced across the plate and a second series of slots (46A, 46B) spaced across the plate, each slot (36A, 36B) of the first series being positioned between a pair of slots (46A, 46B) of the second series and each slot (46A, 46B) of the second series opening at one of its two ends into a feeder slot (50, 50B) extending across the second plate, the feeder slot thereby connecting those first ends together.



A
12
18
34
34
34
30A
32
30
VIII
VIII
26A
10
28
26
20
VII
VII
24
24
24
22
20
18
16
14
A

FIG. 1

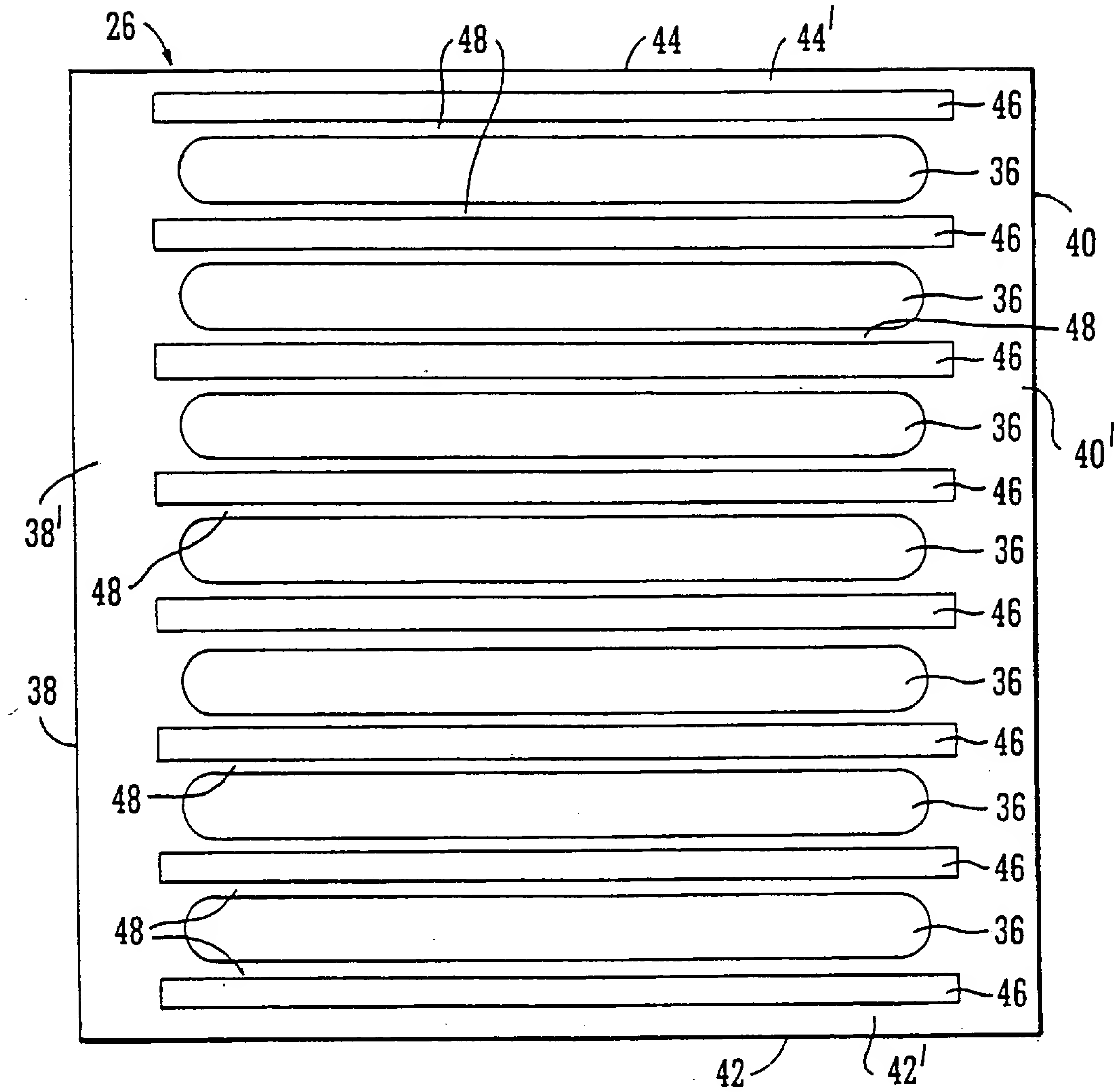
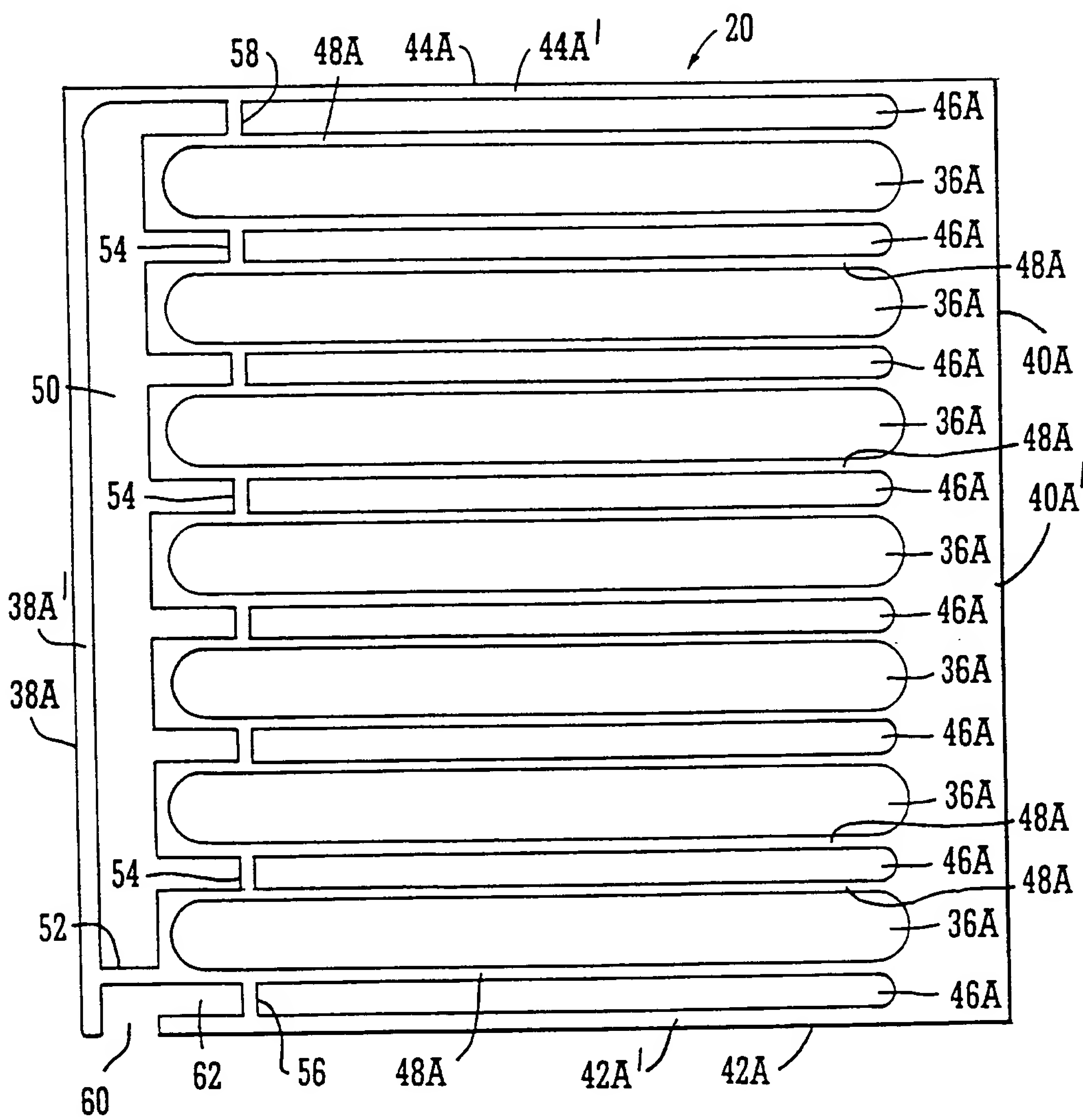


FIG. 2



20
58
48A
44A
44A'
46A
36A
46A
48A
36A
40A
46A
36A
48A
46A
40A'
36A
46A
36A
46A
36A
48A
46A
48A
36A
46A
54
50
54
38A'
38A
54
52
60
62
56
48A
42A'
42A

FIG. 3

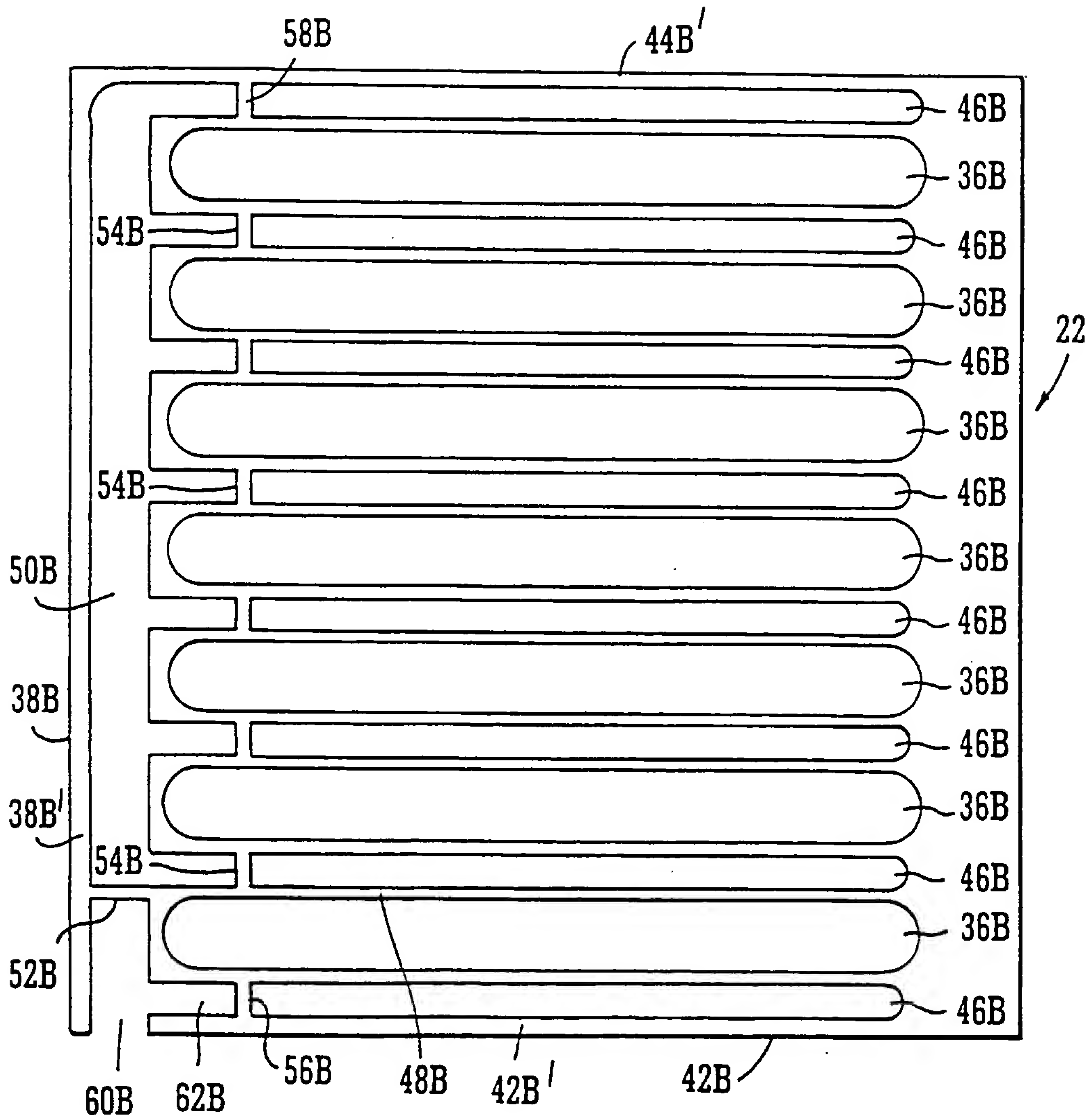

58B
44B'
46B
36B
54B
46B
36B
22
46B
36B
54B
46B
36B
50B
46B
36B
38B
46B
36B
38B'
54B
46B
36B
52B
46B
60B
62B
56B
48B
42B'
42B

FIG. 4

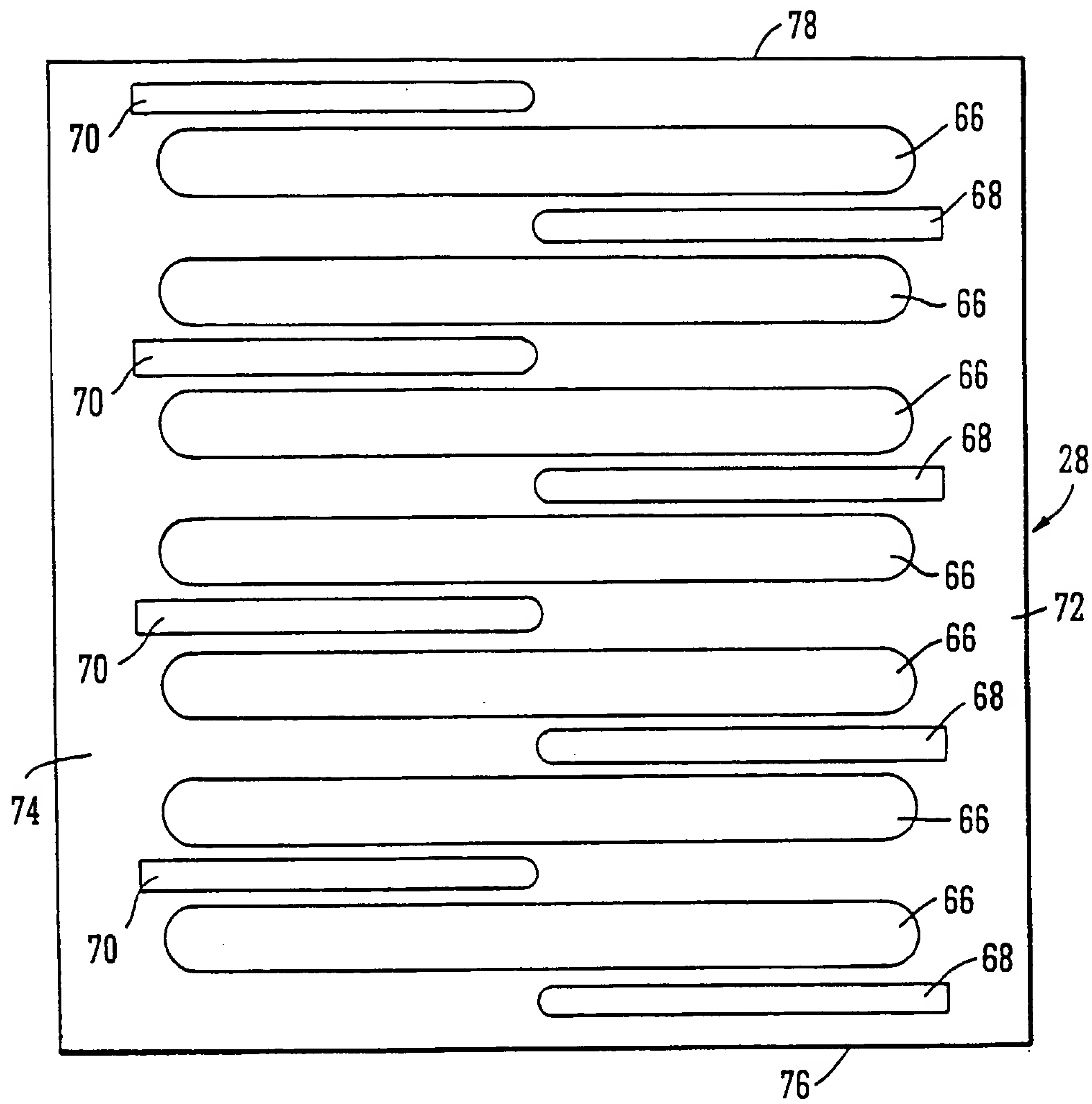


FIG. 5

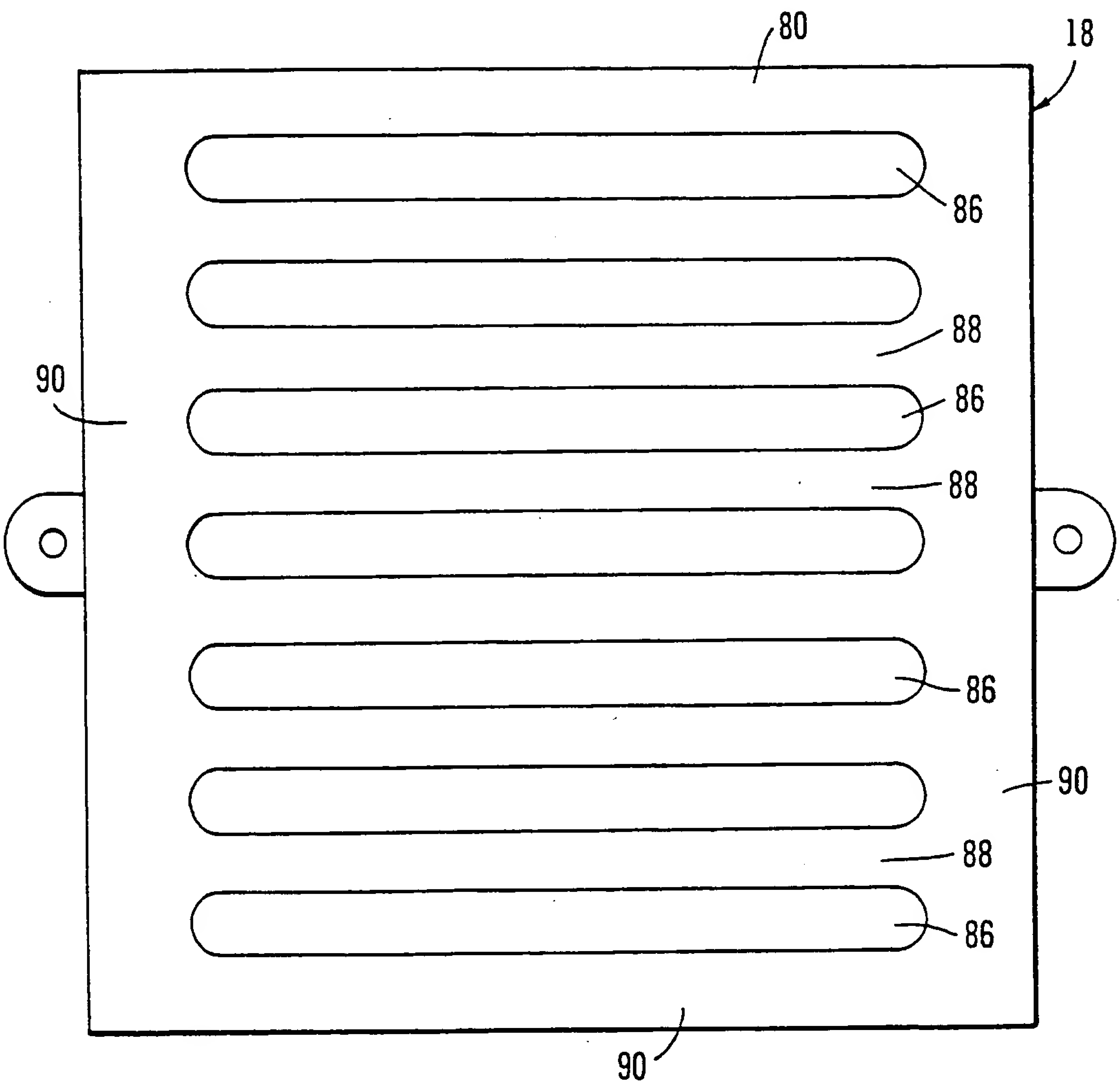


FIG. 6

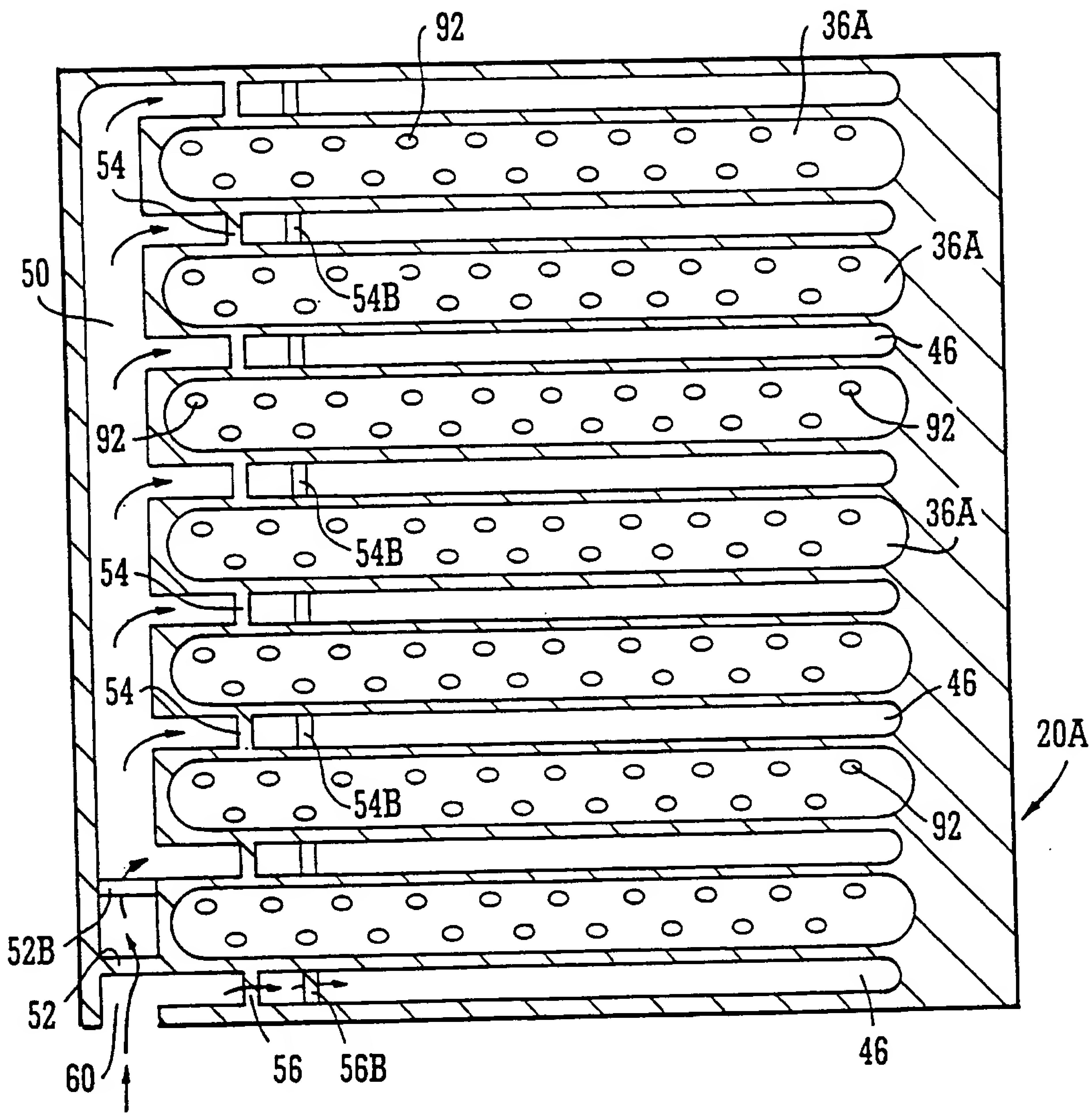
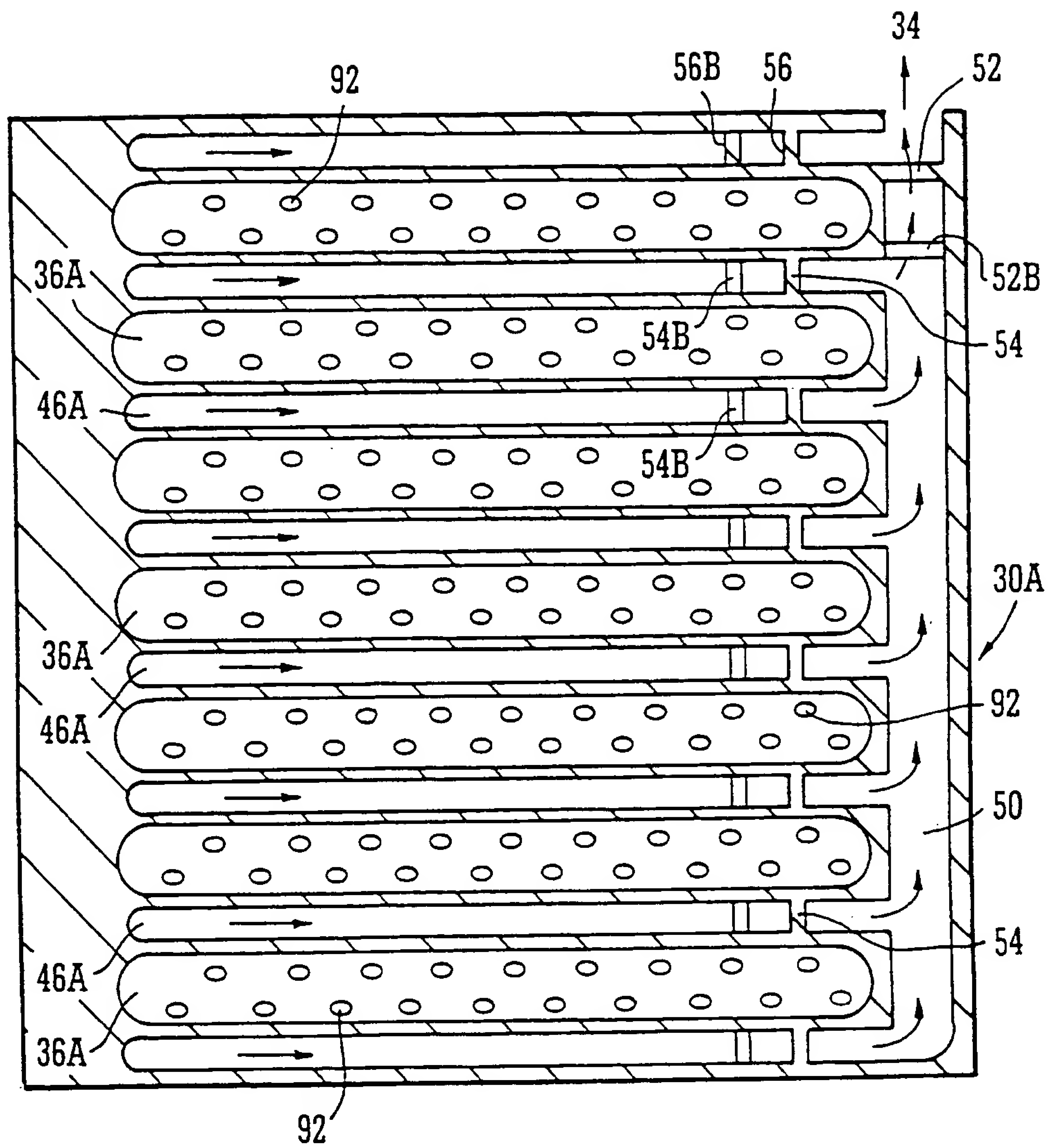

92
36A
54
50
54B
36A
46
92
92
54B
36A
54
54
46
20A
54B
92
52B
52
60
56
56B
46

FIG. 7


34
52
56B
56
92
52B
36A
54B
54
46A
54B
30A
36A
46A
92
50
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46A
36A
92

FIG. 8

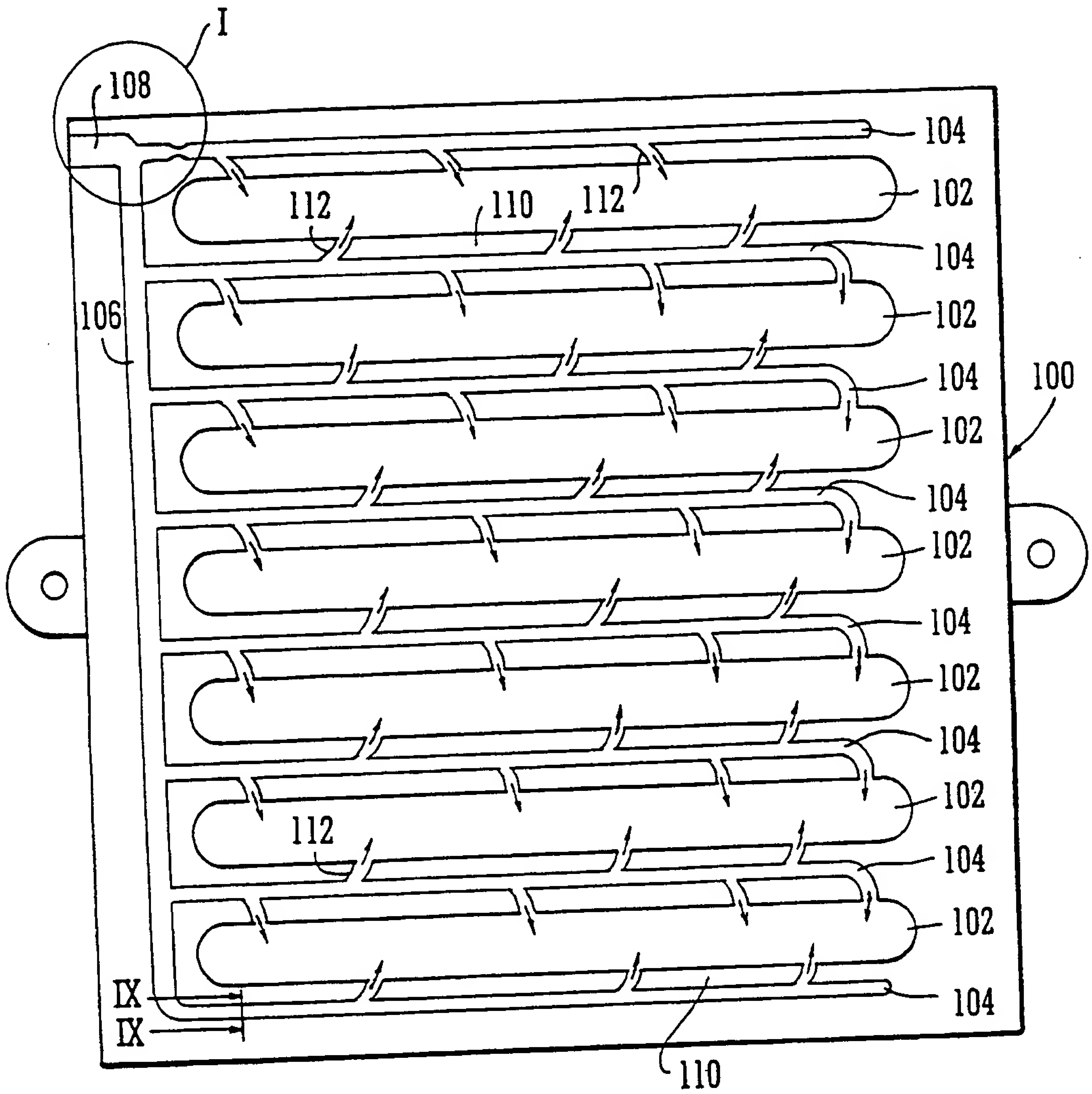

FIG. 9

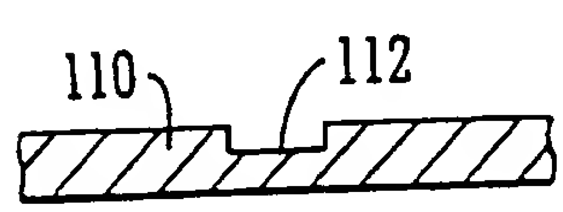

FIG. 9A

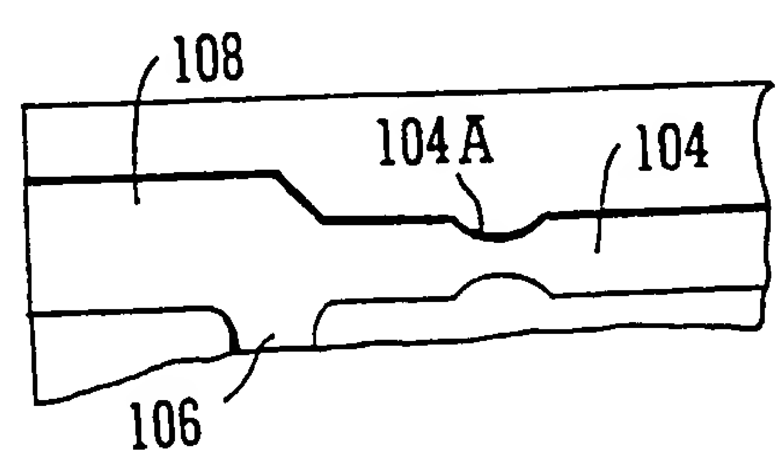

FIG. 9B

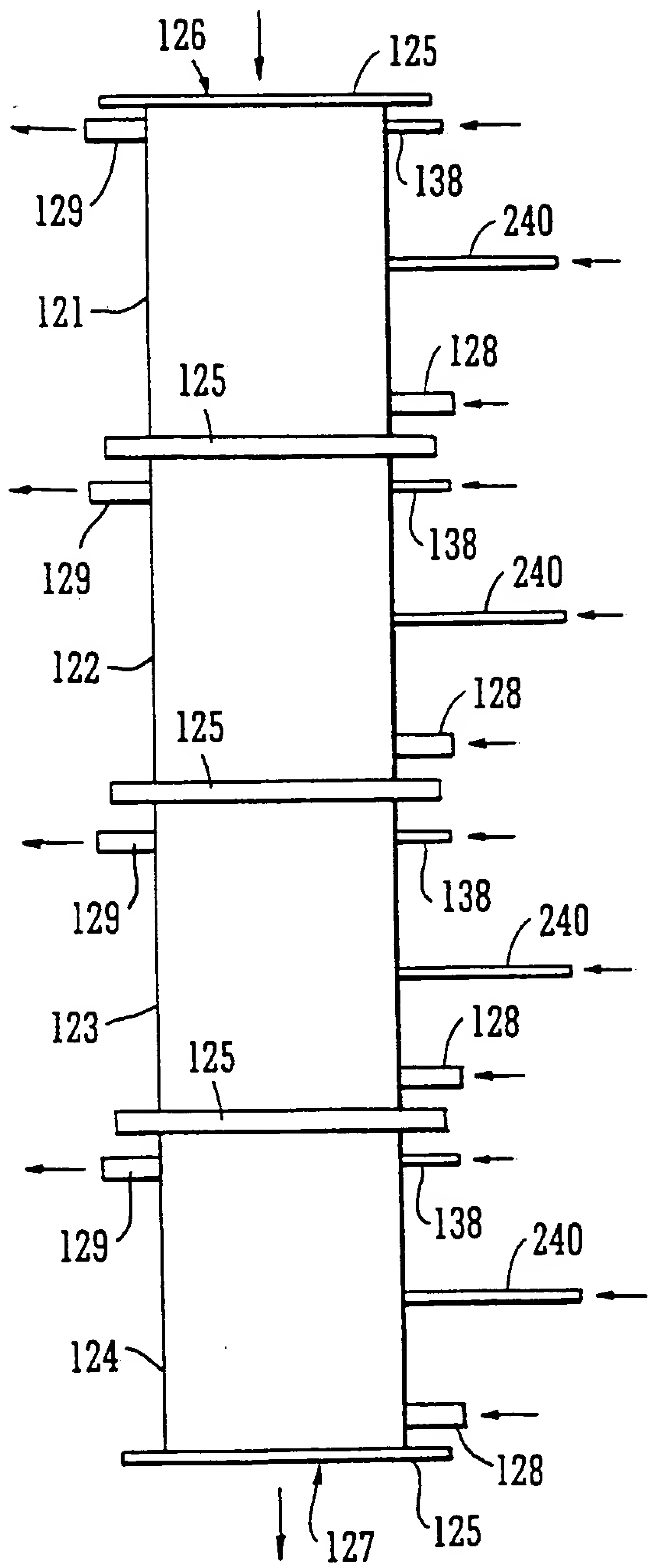
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FIG. 10

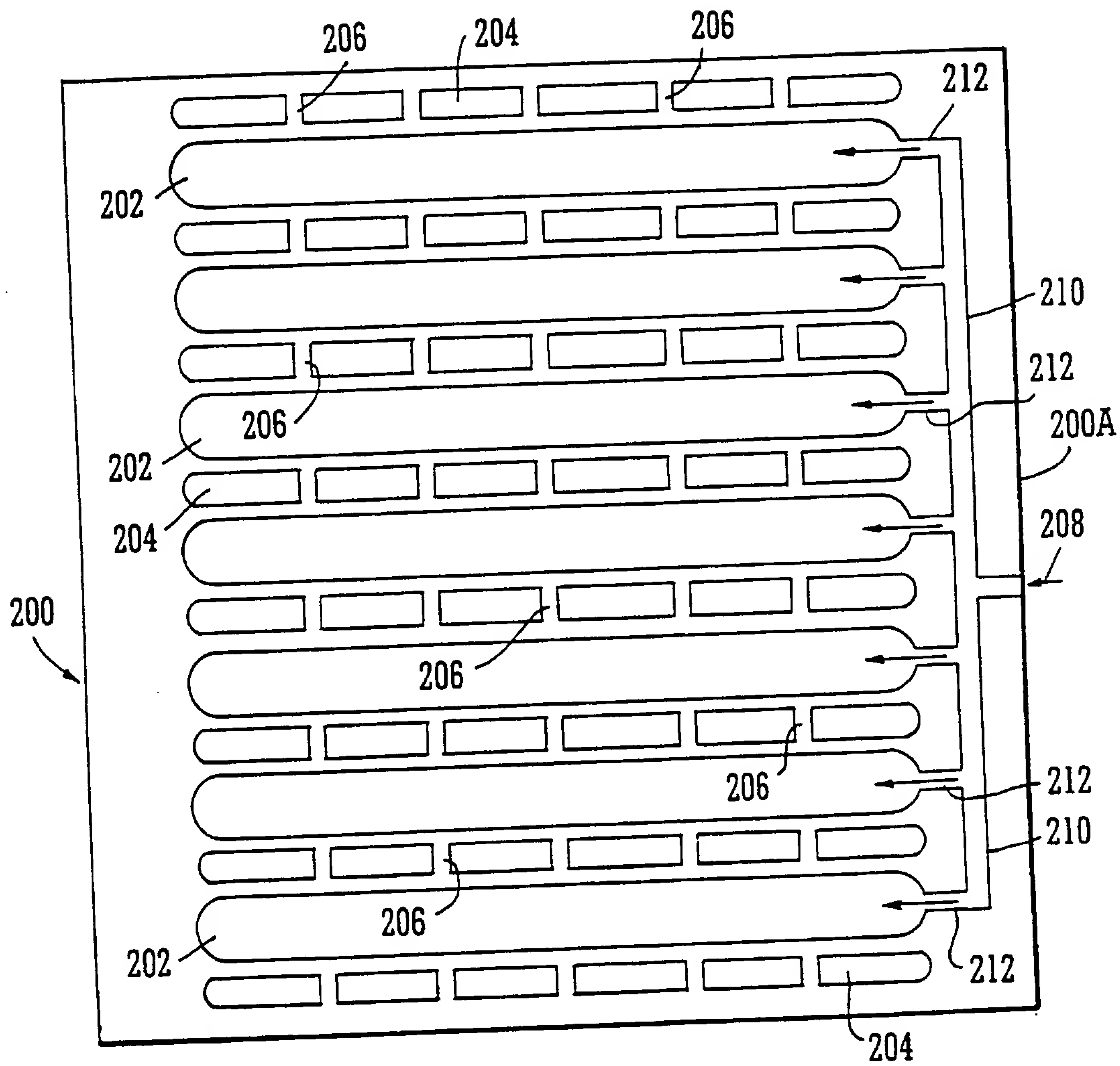
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FIG. 11

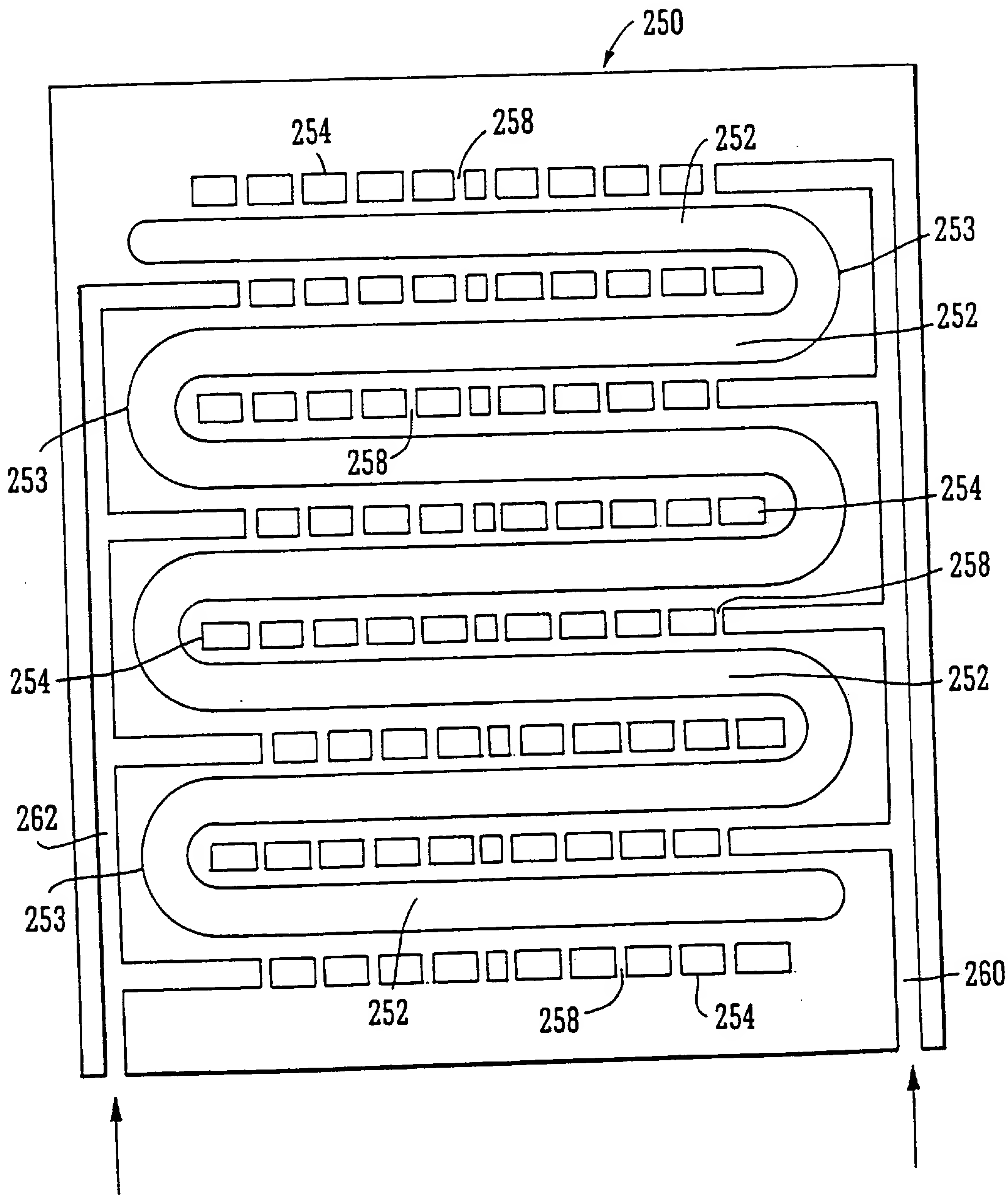
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FIG. 12

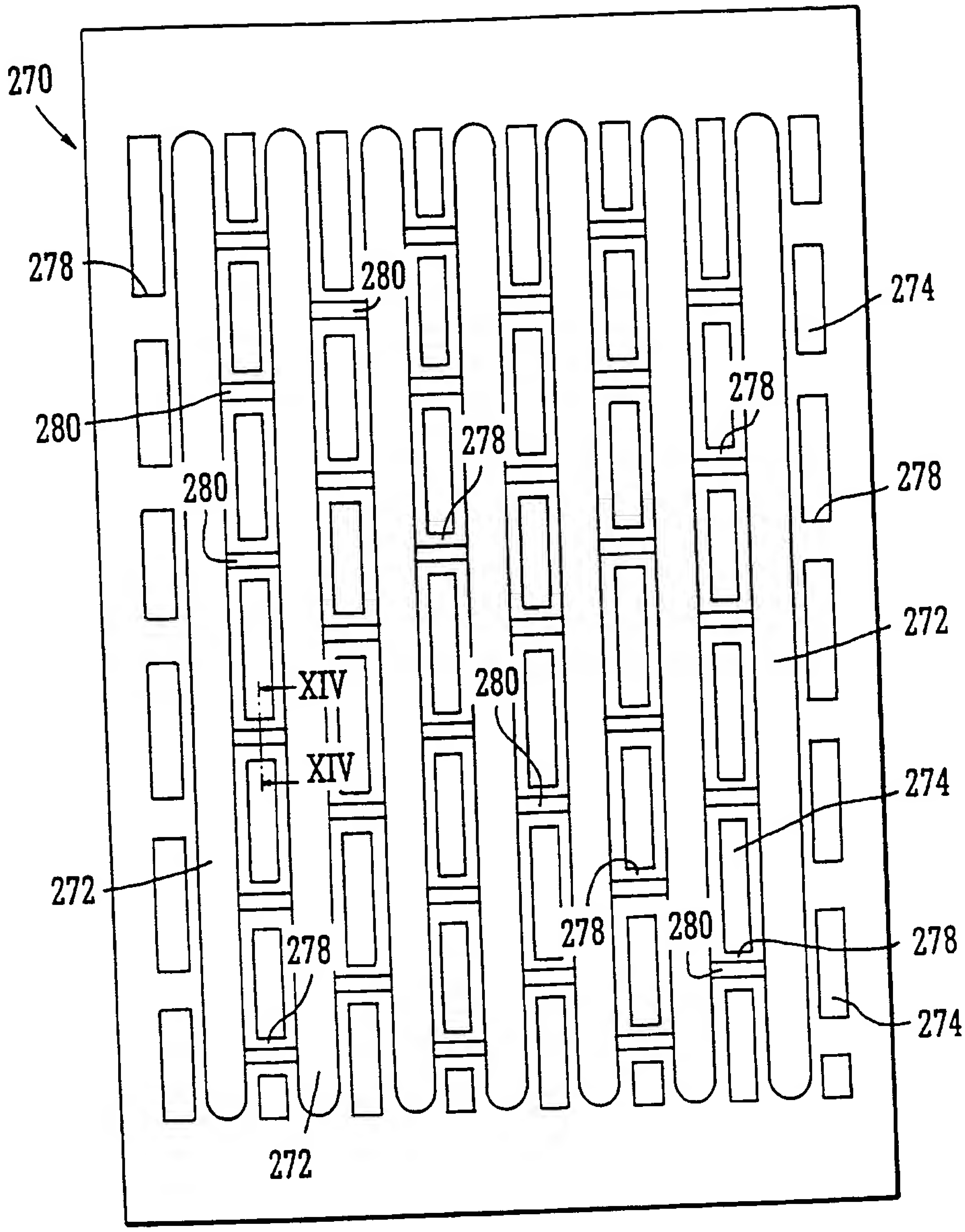
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FIG. 13

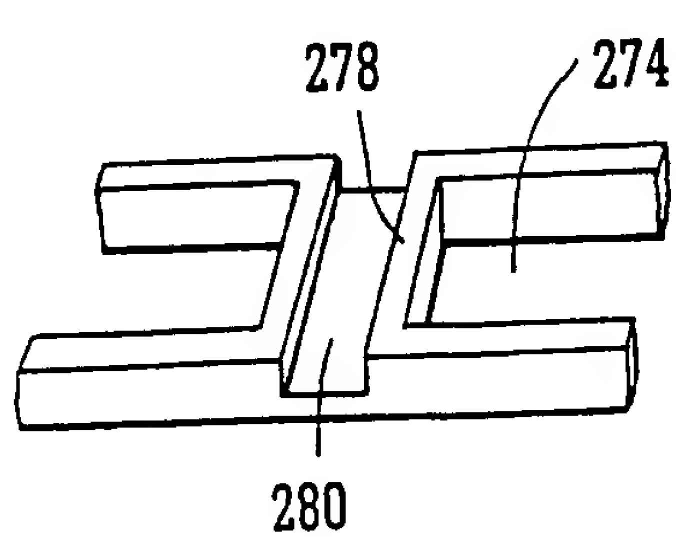
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FIG. 14

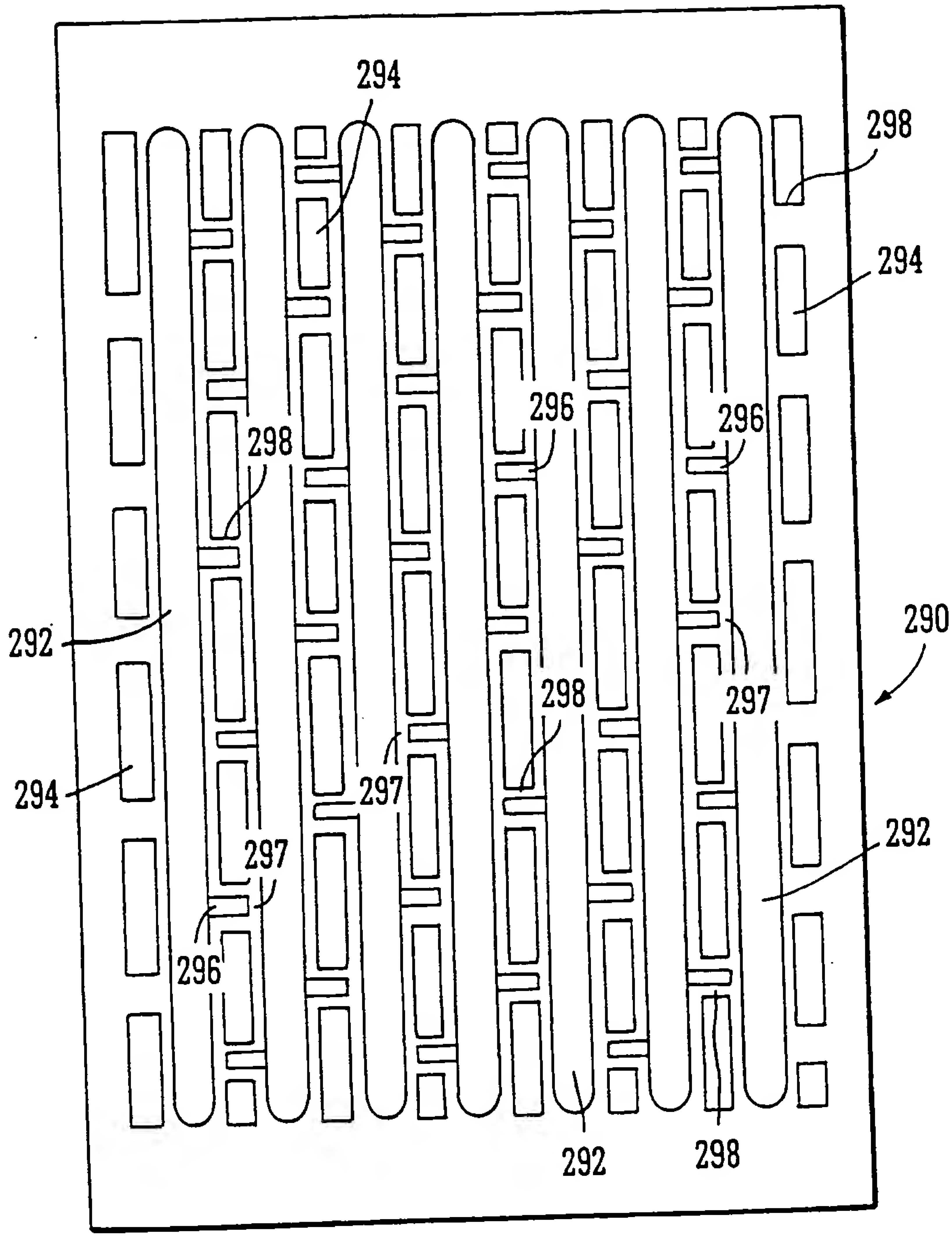
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FIG. 15

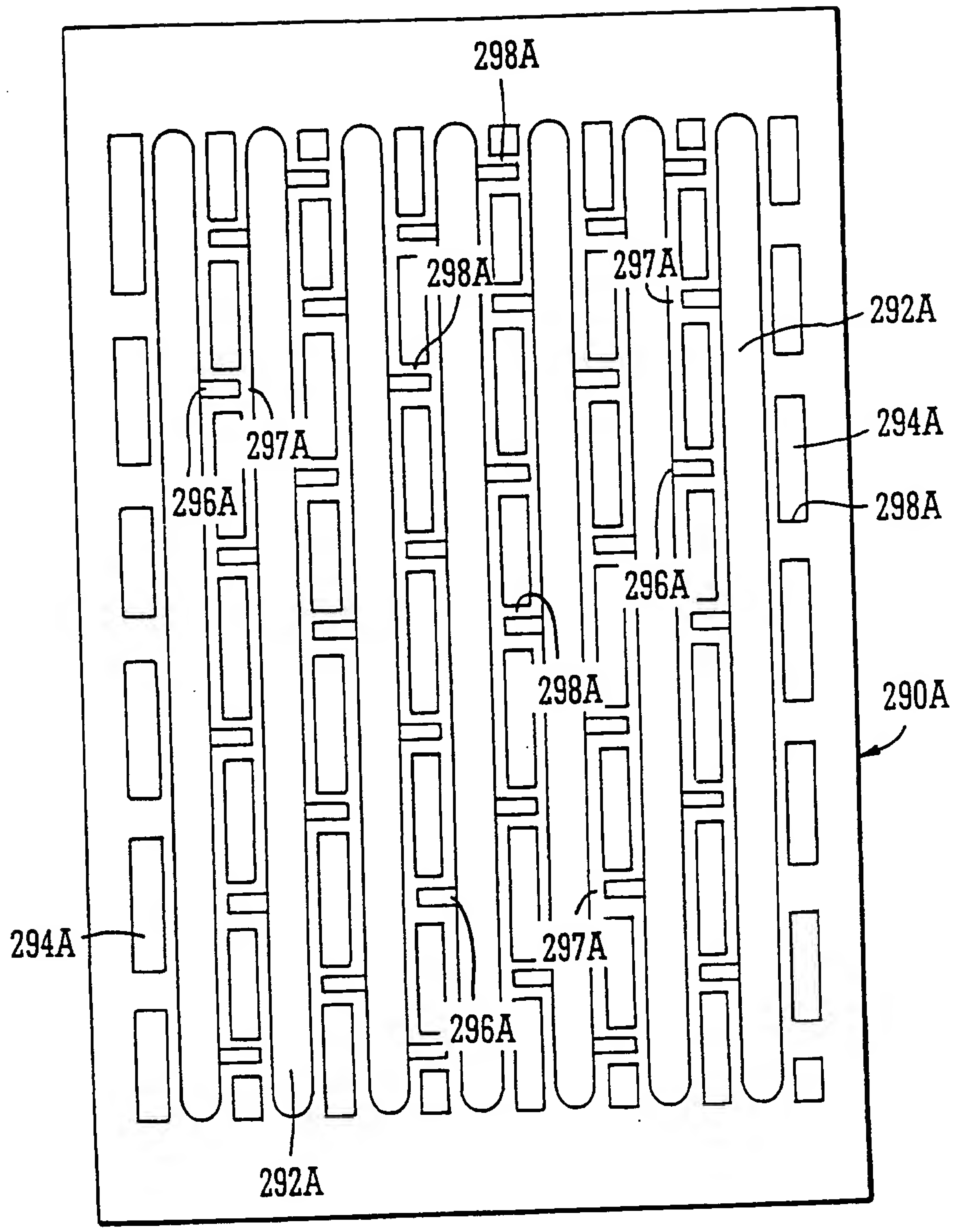
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FIG. 16

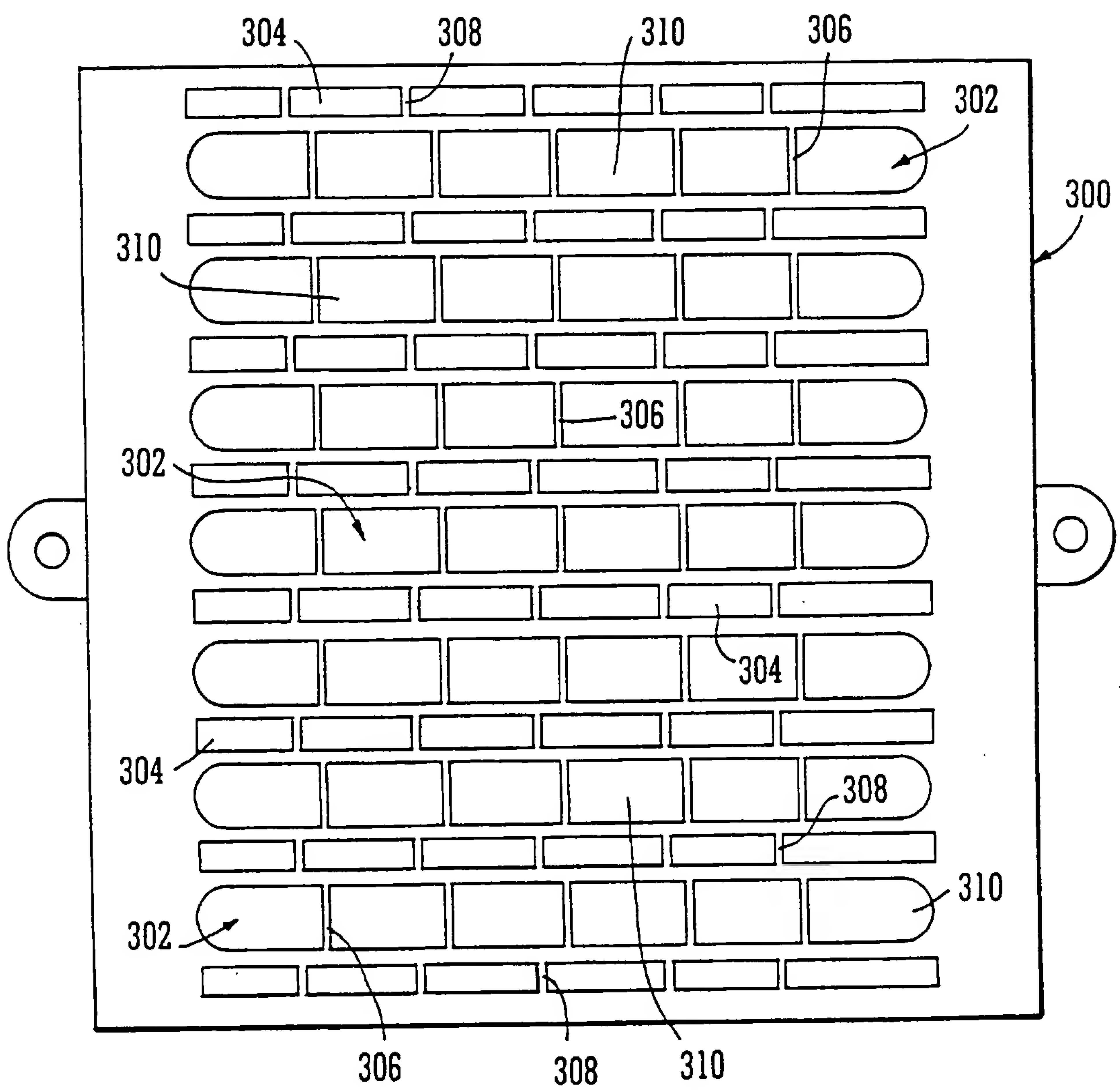
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FIG. 17

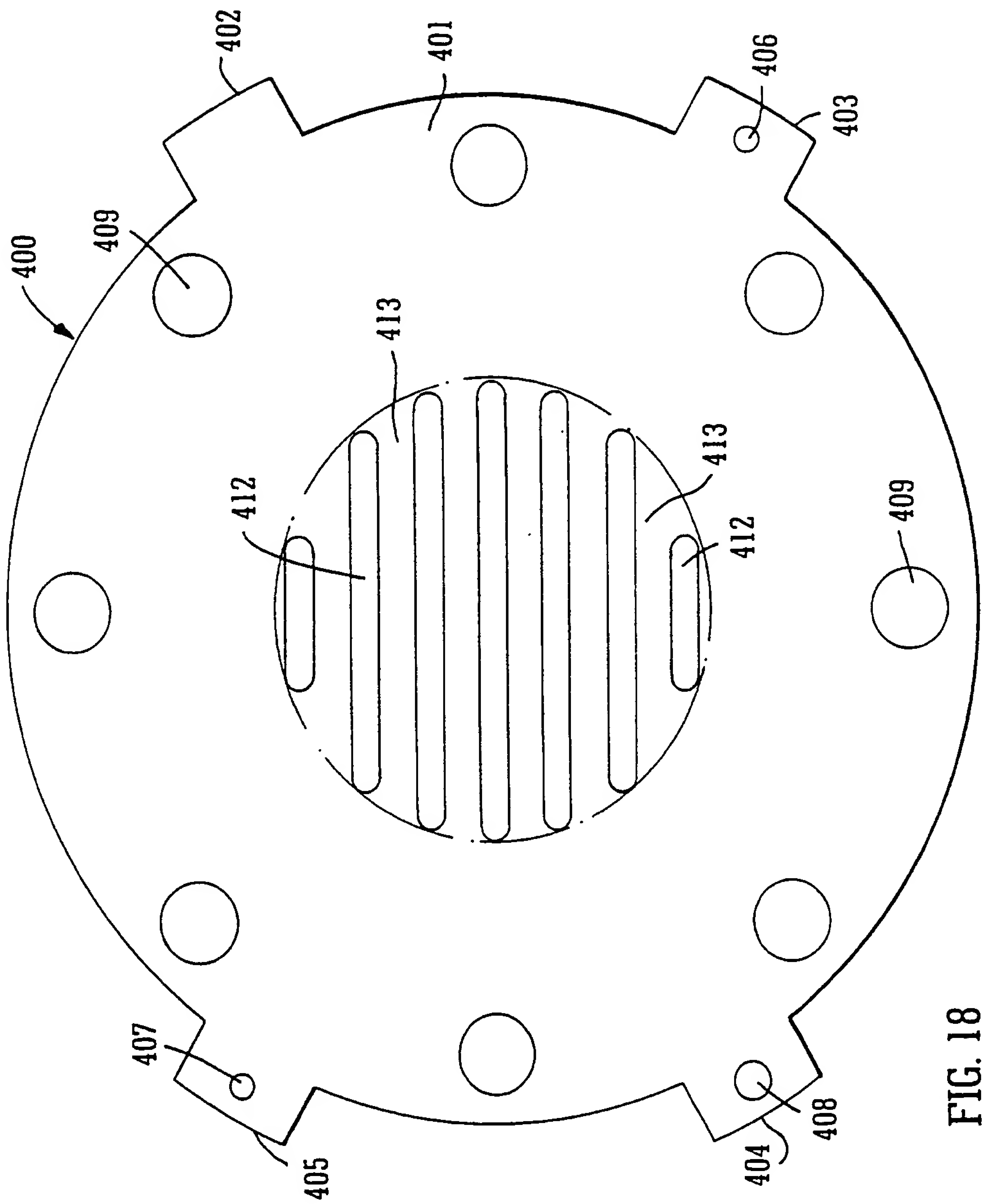

FIG. 18

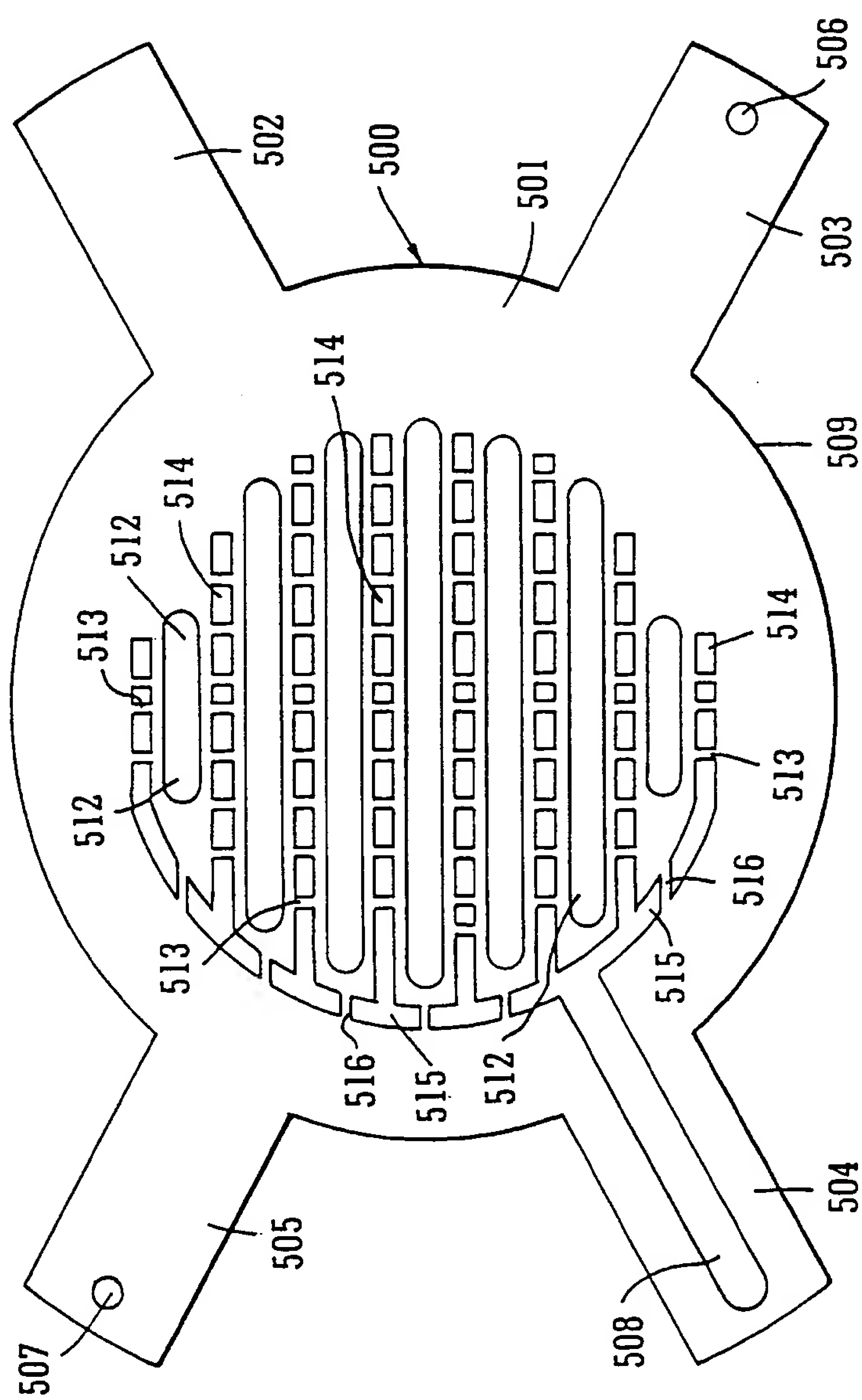

FIG. 19

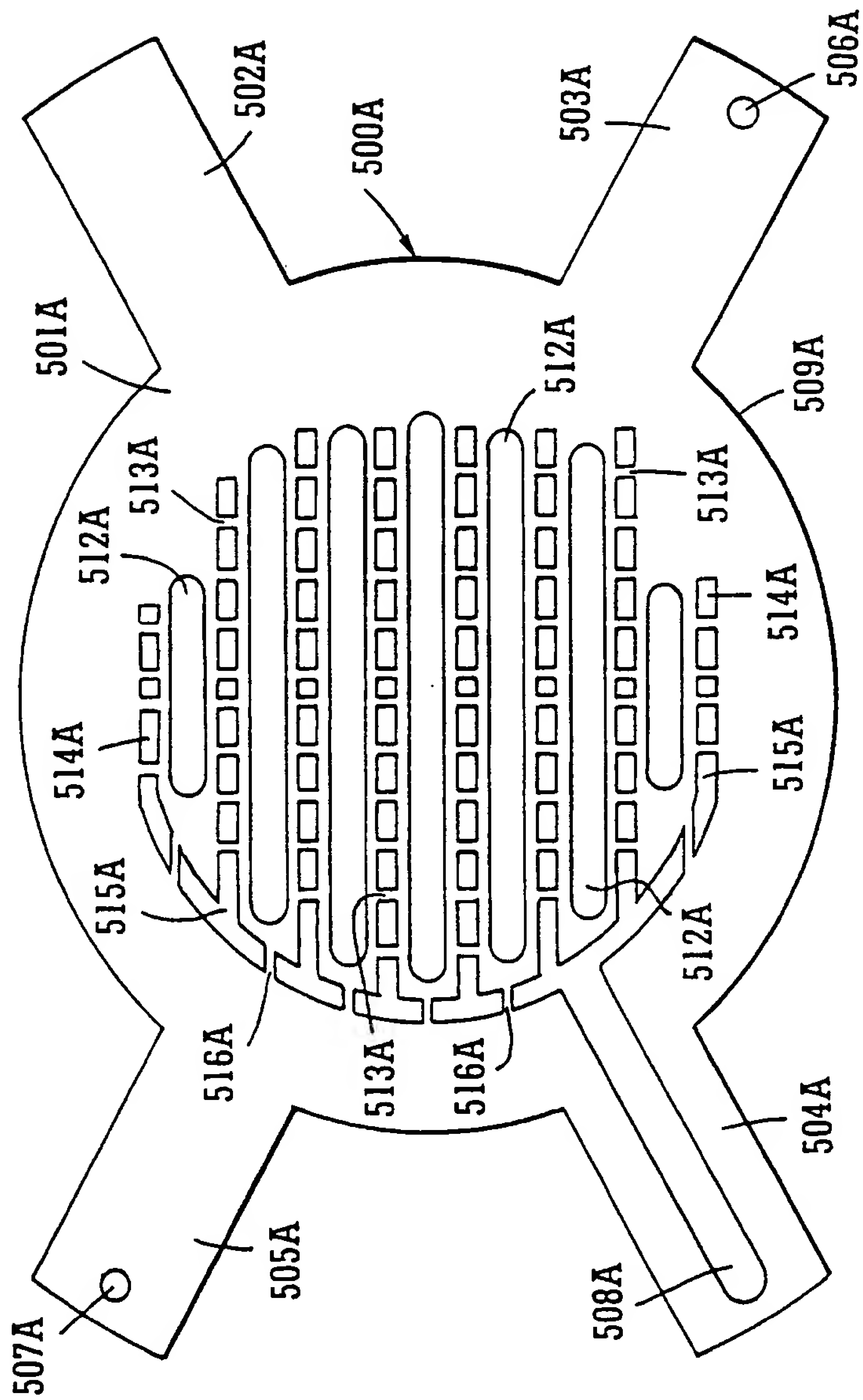
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FIG. 20

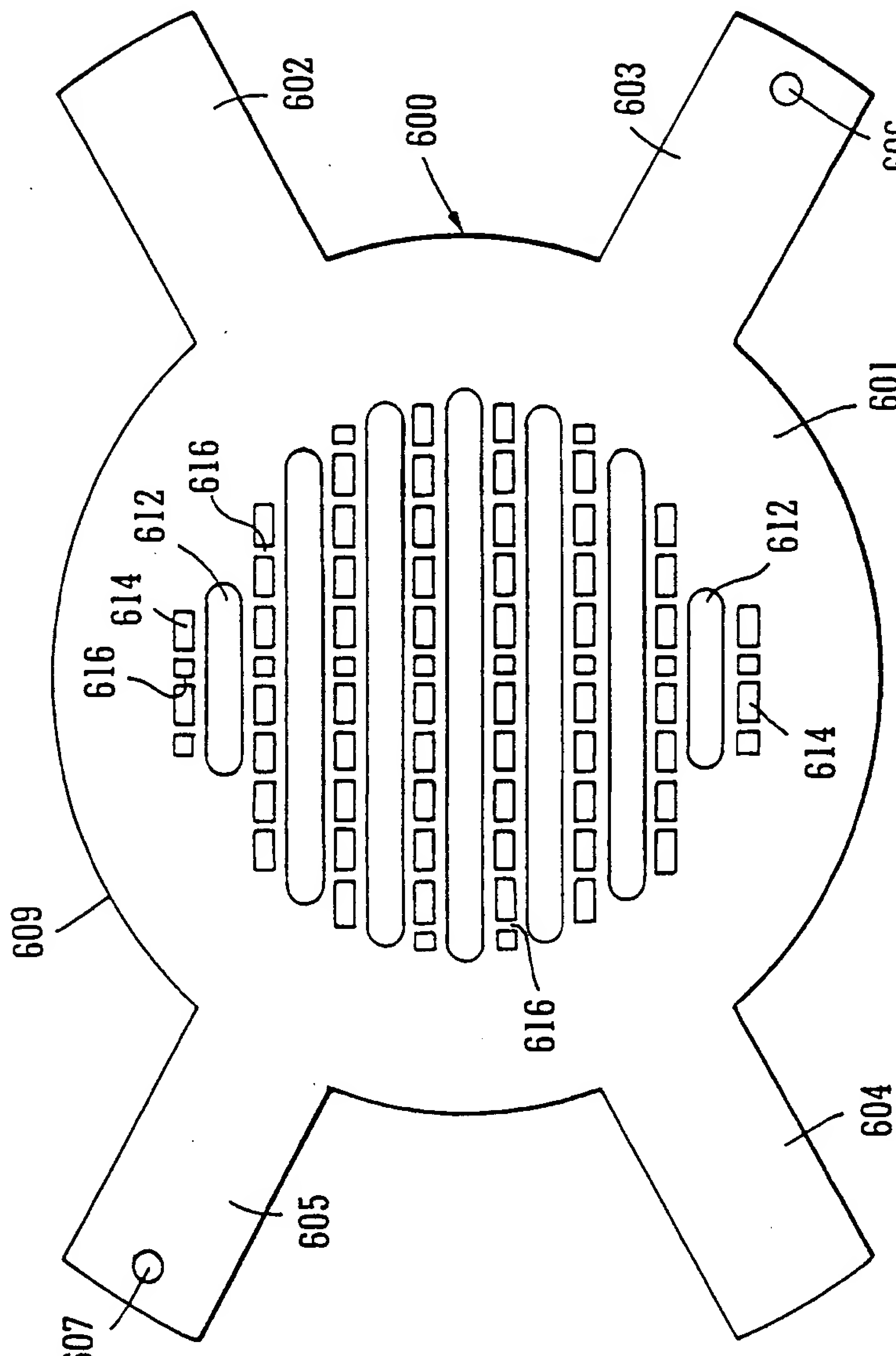

FIG. 21

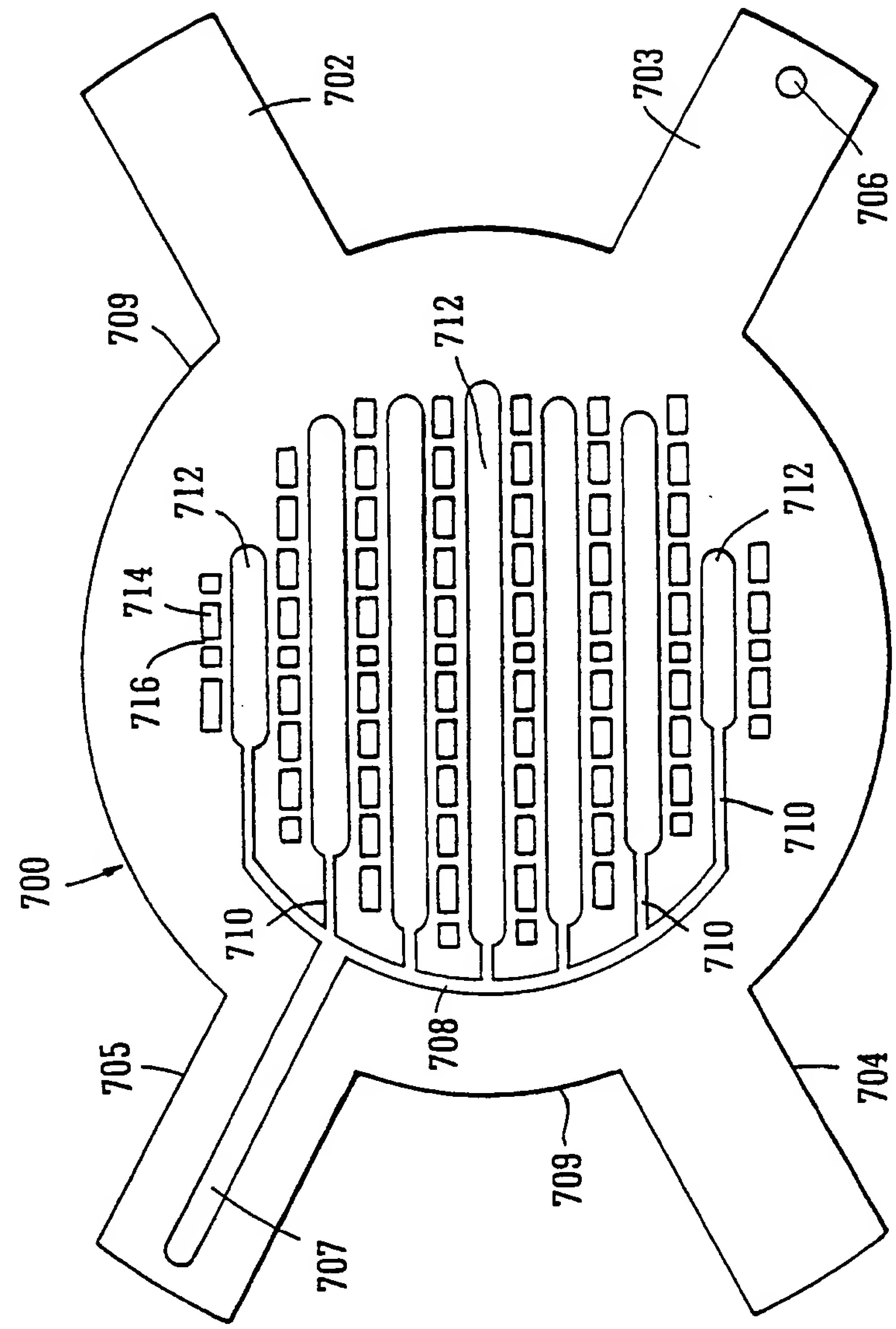
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FIG. 22

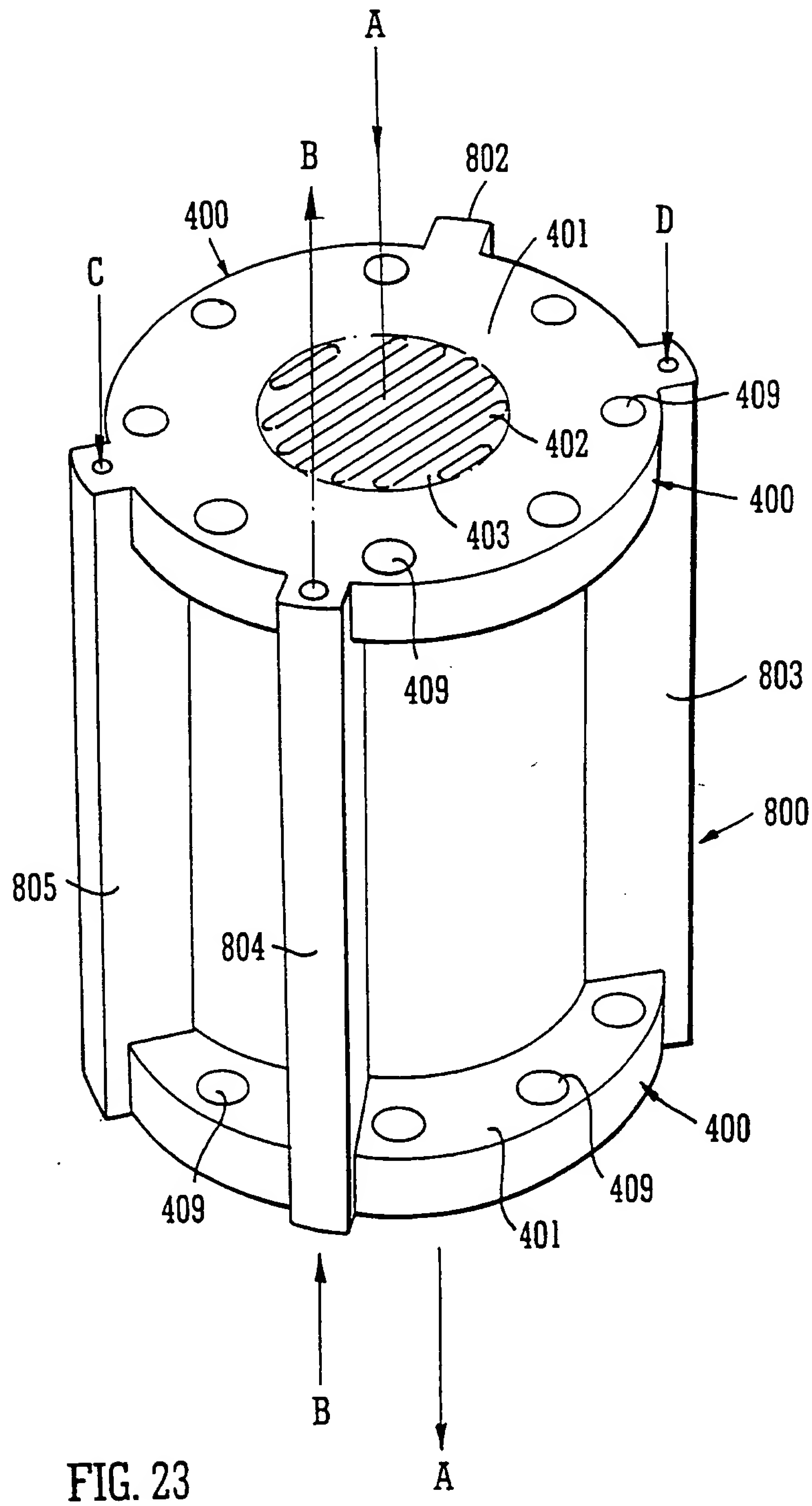
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FIG. 23

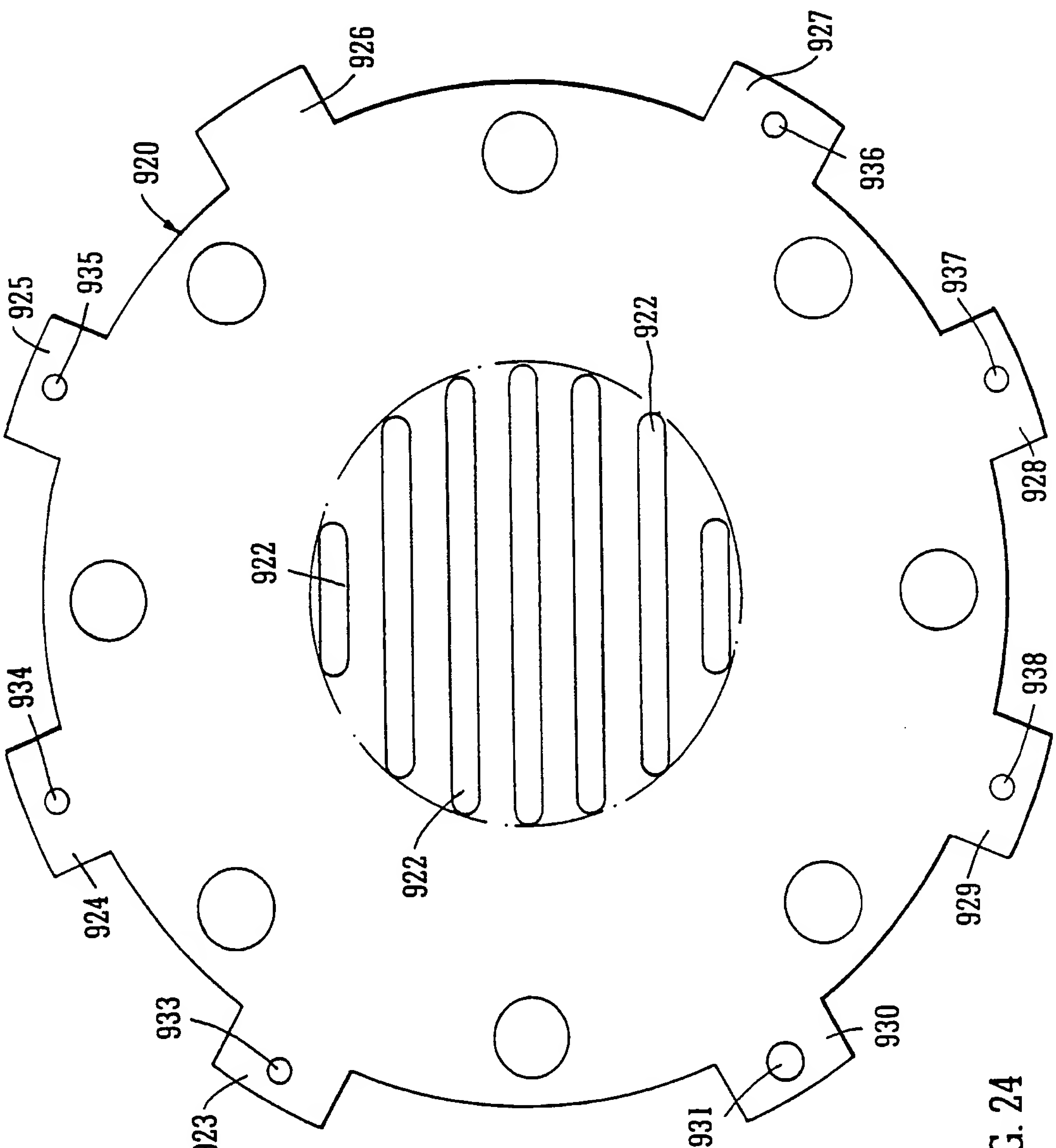
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FIG. 24

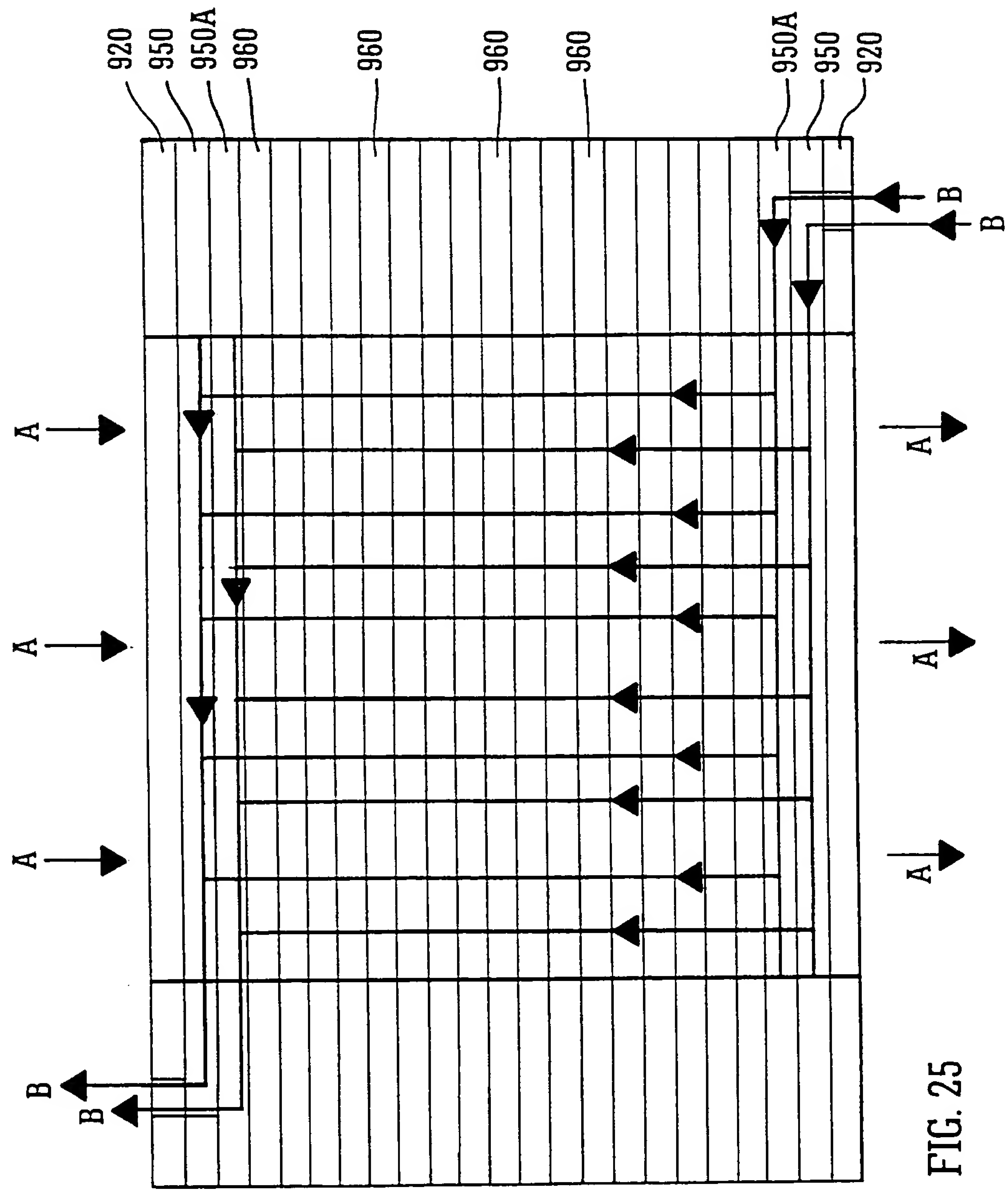

FIG. 25

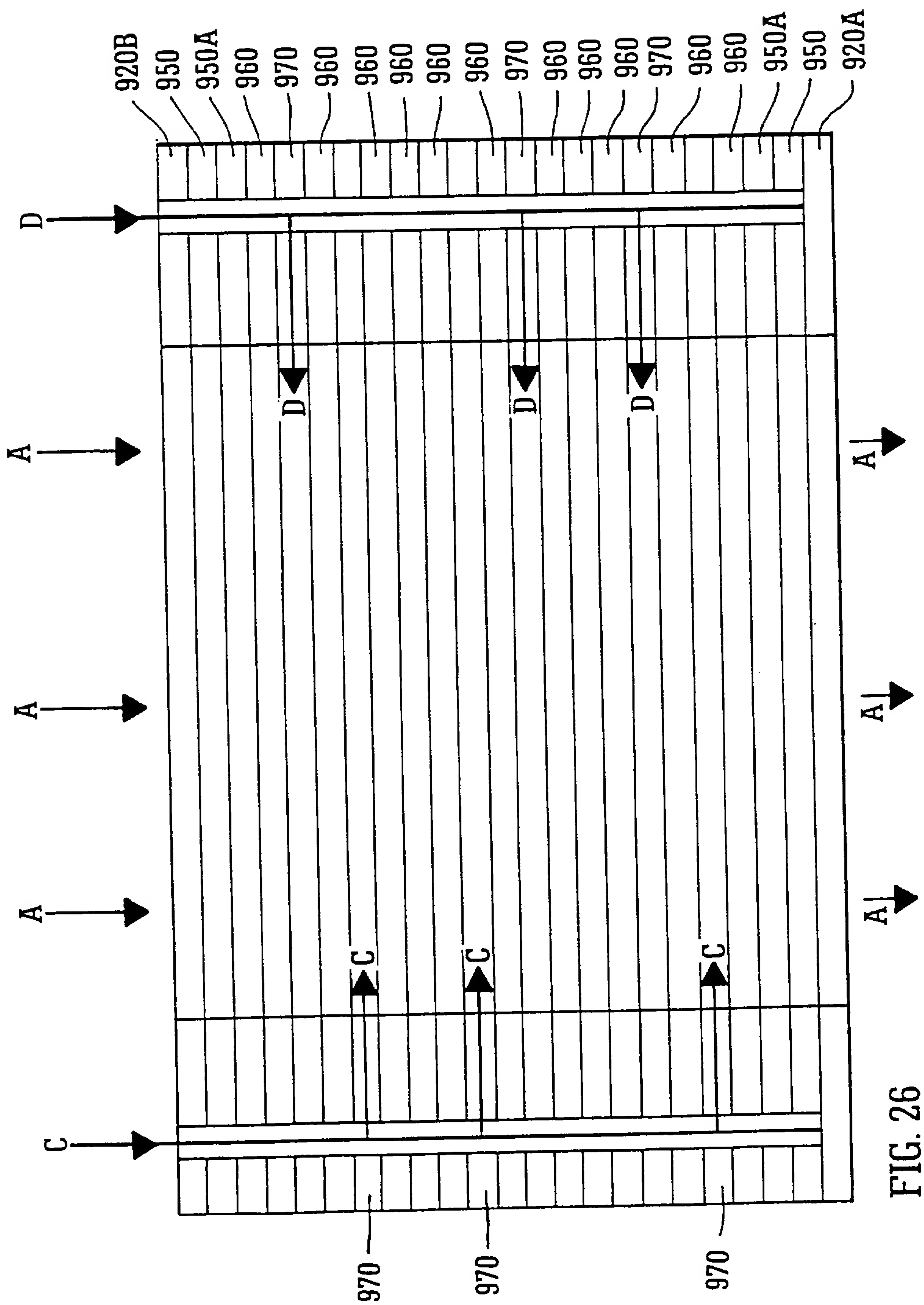
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FIG. 26

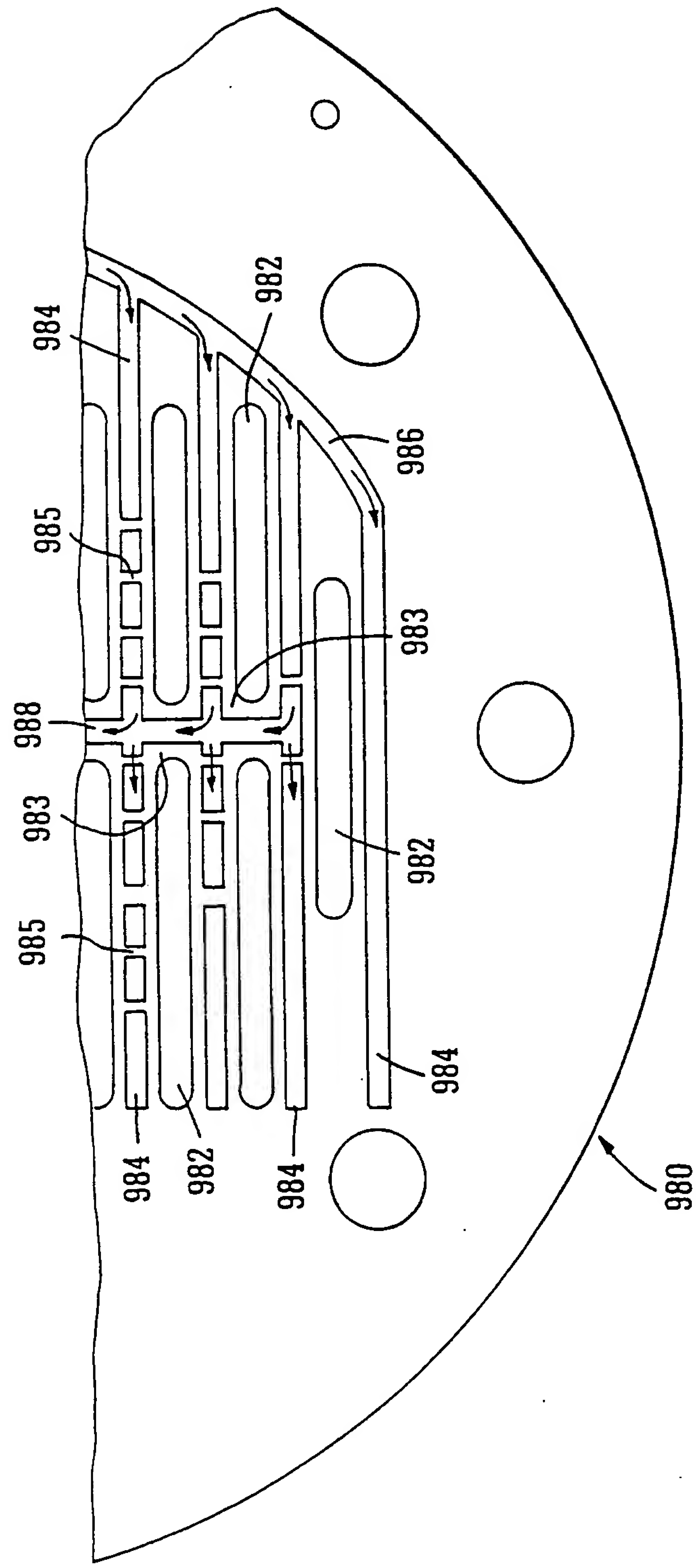

FIG. 27

INTERNATIONAL SEARCH REPORT

Int. .tional Application No
PCT/GB 99/04131

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F28D9/00 F28F3/08 B01J8/02 B01J8/04 B01J19/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F28D F28F B01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 691 967 A (AIRPREHEATER CORPORATION) 27 May 1953 (1953-05-27) page 2, line 5 -page 3, line 49; figures ---	1,5,15, 16,25,26
A	DE 20 08 976 A (GENERAL ELECTRIC COMPANY) 17 September 1970 (1970-09-17) claims; figures ---	1,10,26
A	GB 1 484 124 A (ASS ENG LTD) 24 August 1977 (1977-08-24) page 1, line 87 -page 2, line 83; figures 1,2 ---	1-26
A	US 5 727 618 A (MUNDINGER DAVID C ET AL) 17 March 1998 (1998-03-17) column 6, line 39 -column 8, line 47; figures ---	1-26

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search	Date of mailing of the international search report
27 March 2000	07/04/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Mootz, F

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International Application No
PCT/GB 99/04131

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 196 54 361 A (BEHR GMBH & CO) 25 June 1998 (1998-06-25) abstract; figure 1	1,4,5,26
A	EP 0 206 935 A (INST FRANCAIS DU PETROL) 30 December 1986 (1986-12-30) abstract; figures	1,26
A	EP 0 597 398 A (HOECHST CERAM TEC AG) 18 May 1994 (1994-05-18) abstract; figures	1,26

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 99/04131

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